Biological Services Program

FWS/OBS-78/76

DE
MAR
CLEMSO
LIBRARY

CLASSIFICATION, INVENTORY, AND ANALYSIS OF FISH AND WILDLIFE HABITAT

The Proceedings of a National Symposium

Fish and Wildlife Service

U.S. Department of the Interior

The Biological Services Program was established within the U.S. Fish and Wildlife Service to supply scientific information and methodologies on key environmental issues that impact fish and wildlife resources and their supporting ecosystems. The mission of the program is as follows:

- To strengthen the Fish and Wildlife Service in its role as a primary source of information on national fish and wildlife resources, particularly in respect to environmental impact assessment.
- To gather, analyze, and present information that will aid decisionmakers in the identification and resolution of problems associated with major changes in land and water use.
- To provide better ecological information and evaluation for Department of the Interior development programs, such as those relating to energy development.

Information developed by the Biological Services Program is intended for use in the planning and decisionmaking process to prevent or minimize the impact of development on fish and wildlife. Research activities and technical assistance services are based on an analysis of the issues, a determination of the decisionmakers involved and their information needs, and an evaluation of the state of the art to identify information gaps and to determine priorities. This is a strategy that will ensure that the products produced and disseminated are timely and useful.

Digitized by the Internet Archive
in 2013

Projects have been initiated in the following areas: coal extraction and conversion; power plants; geothermal, mineral, and oil shale development; water resource analysis, including stream alterations and western water allocation; coastal ecosystems and Outer Continental Shelf development; and systems and inventory, including National Wetland Inventory, habitat analysis, and technology transfer.

The Biological Services Program consists of the Office of Biological Services in Washington, D.C., which is responsible for overall planning and management; National Teams, which provide the Program's central scientific and technical expertise and arrange for contracting biological services studies with states, universities, consulting firms, and others; Regional Teams, which provide a link to problems at the operating level; and staff at certain Fish and Wildlife Service research facilities, who conduct inhouse research studies.

http://archive.org/details/classificationin00depa

FWS/OBS - 78/76

Classification, Inventory, And Analysis Of Fish And Wildlife Habitat

Proceedings of a National Symposium
Phoenix, Arizona
January 24-27, 1977

General Chairman

Allan Marmelstein, Project Leader
Habitat Analysis
Office of Biological Services
Fish and Wildlife Service

Sponsored by

Office of Biological Services
Fish and Wildlife Service
U.S. Department of the Interior
Washington, D.C. 20240

DISCLAIMER

The opinions, findings, conclusions, or recommendations expressed in this product are those of the authors and do not necessarily reflect the views of the Office of Biological Services, Fish and Wildlife Service, U.S. Department of the Interior, nor does mention of trade names or commercial products constitute endorsement or recommendation for use by the federal government.

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

Stock Number 024-010-00503-3

Table of Contents

1 INTRODUCTION — Allan Marmelstein

3 WELCOMING ADDRESS — Lynn Greenwalt

SESSION I: USER NEEDS

Chairman: Gerard Bertrand
Council on Environmental Quality

5 HABITAT DATA NEEDS FOR MANAGING WILDLIFE — Laurence R. Jahn

13 MANY USES AND MANY USERS: SOME DESIRABLE CHARACTERISTICS OF A COMMON LAND AND WATER CLASSIFICATION SYSTEM — Lawrence S. Davis, Jan A. Henderson

35 NATIONAL ASSESSMENT NEEDS — Richard S. Driscoll

41 CLASSIFICATION AND INVENTORY FOR THE PERPETUATION OF ECOLOGICAL DIVERSITY — Robert E. Jenkins

53 HABITAT CLASSIFICATION AND THE REGULATION OF CRITICAL NEEDS — Jon A. Kusler

SESSION II: CLASSIFICATION SYSTEMS

Chairman: Lawrence Davis
Utah State University

59 THE DILEMMA OF STREAM CLASSIFICATION — Robert W. Pennak

67 LAKE CLASSIFICATION — GOOD AND BAD — Gerald A. Cole

79 CLASSIFICATION OF COASTAL ENVIRONMENTS — John Clark

103 INSULAR AQUATIC ECOSYSTEMS: HAWAII — J.A. Maciolek

121 A NEW MAP OF THE ECOSYSTEM REGIONS OF THE UNITED STATES — Robert G. Bailey

129 A PHYSIOGRAPHIC — PHOTOMORPHIC TECHNIQUE OF HABITAT CLASSIFICATION — E.J. Hodgkins, T.K. Cannon

137 THE IUCN DIRECTORY OF WETLANDS OF INTERNATIONAL IMPORTANCE — Erik Carp

145 THE CANADIAN EXPERIENCE: AN APPROACH TOWARD BIOPHYSICAL INTERPRETATION — Dennis A. Demarchi, Thomas W. Chamberlain

165 U.S. FISH AND WILDLIFE SERVICE WETLAND CLASSIFICATION — STATUS, 1977 — Lewis M. Cowardin

173 DATA REQUIREMENTS FOR TERRESTRIAL WILDLIFE HABITAT INVENTORY — Richard Kerr, Kenneth Brown

179 THE RPA-80 LAND CLASSIFICATION SYSTEM — Jack E. Schmautz

187 A DIGITIZED CLASSIFICATION SYSTEM FOR THE NATURAL VEGETATION OF NORTH AMERICA WITH HIERARCHICAL SUMMARY FOR WORLD ECOSYSTEMS — David E. Brown, Charles H. Lowe, Charles P. Pase

221	EVALUATION OF HABITAT QUALITY IN WYOMING TROUT STREAMS	N. Allen Binns
243	NATURAL AREA CLASSIFICATION SYSTEM: A STANDARDIZATION SCHEME FOR BASIC INVENTORY OF SPECIES, COMMUNITY, AND HABITAT DIVERSITY	Albert E. Radford

SESSION III: ECOLOGICAL RELATIONSHIPS

Chairman: Joseph Larson
University of Massachusetts

281	THE RELATIONSHIP OF TERRESTRIAL VERTEBRATES TO PLANT COMMUNITIES AND THEIR SUCCESSIONAL STAGES	Jack Ward Thomas Rod Miller Chris Maser Ralph Anderson Bernie Carter
305	ASSESSMENT OF HABITAT CONDITION BY MEASUREMENT OF BIOCHEMICAL AND ENDOCRINE INDICATORS OF THE NUTRITIONAL, REPRODUCTIVE, AND DISEASE STATUS OF FREE-RANGING ANIMAL POPULATIONS	U.S. Seal
331	A DATA COMPILATION PROGRAM FOR WETLAND EVALUATION	J.K. Dueker T.W. Haislip, Jr.
351	ENVIRONMENTAL VALUE MAPPING: AN INDISPENSABLE TOOL OR TRAP?	Carlos M. Fetterolf, Jr.
363	HIGHWAYS AND WILDLIFE: IMPLICATIONS FOR MANAGEMENT	Daniel L. Leedy
385	USE OF CRITICAL PARAMETERS FOR EVALUATING WILDLIFE HABITAT	Rollin D. Sparrowe Bettina Flood Sparrowe
407	THE HABITAT EVALUATION PROCEDURES	Adrian H. Farmer
421	IDENTIFICATION OF CRITICAL WILDLIFE HABITAT USING AN "IMPACT RISK" MAPPING TECHNIQUE	Larry S. Thompson
443	ECOSYSTEM TROPHIC RELATIONSHIPS IN HABITAT CLASSIFICATION	Norman R. French
461	EFFECTS OF THE INSULARIZATION OF THE EASTERN DECIDUOUS FOREST ON AVIFAUNAL DIVERSITY AND TURNOVER	James F. Lynch Robert F. Whitcomb
491	HABITAT SCARCITY, A BASIS FOR ASSIGNING UNIT VALUES FOR ASSESSMENT OF AQUATIC WILDLIFE HABITAT	James P. Fry William L. Pflieger
495	THE EAST MOJAVE DESERT: AN EXAMPLE OF INVENTORY DESIGN AND HABITAT ANALYSIS	Kristin H. Berry
521	PATTERN RECOGNITION AS A TOOL IN THE ECOLOGICAL ANALYSIS OF HABITAT	Gary L. Williams Kenneth R. Russell William K. Seitz

SESSION IV: INVENTORY METHODOLOGY AND INFORMATION MANAGEMENT SYSTEMS

533	INVENTORY AND DISPLAY OF AQUATIC HABITAT	Albert W. Collotzi Donald K. Dunham

543	INTEGRATION OF OPERATIONAL REMOTE SENSING SYSTEMS WITH CONVENTIONAL INVENTORY PROCEDURES	H. Dennison Parker
553	A REVIEW OF EXISTING GEOGRAPHICAL INFORMATION SYSTEMS AND SOME RECOMMENDATIONS FOR FUTURE SYSTEMS	J. Curtis Wilcott William A. Gates
569	THE BALANCED ECOGEOGRAPHICAL INFORMATION SYSTEM: A VEHICLE FOR DATA COLLECTION SYSTEMATIZATION AND DISSEMINATION	H.P. Moyseenko J.L. Woodall S.A. Woodall
593	SUMMARY REMARKS	Harry N. Coulombe

INTRODUCTION

Communication among researchers, the conservation community, and resource managers, all of whom share a common interest in the Nation's fish and wildlife resources, continues to suffer from lack of a structured common ground. In recent years many groups and individuals have attempted, with various degrees of success or acceptance, to structure a framework in which information can be exchanged in a mutually accepted fashion. These approaches have often taken the form of ecologically based methods of classifying and analyzing the natural systems upon which fish and wildlife depend. Unfortunately, the absence of a universally accepted glossary for the specific language of ecology and wildlife resource management has impeded progress towards the goals of common data structures and analytical procedures.

The purpose of the Symposium reported in these Proceedings was to assemble, to the extent possible, the various individuals representative of the major directions being pursued in habitat classification and analysis. It was our hope that some progress toward a common direction would be established if the various schools of thought were presented and discussed. Judgment as to the progress made has been left to those who attended and to those of you who use these proceedings.

As General Chairman, I thank the many individuals whose efforts contributed to this Symposium. I would especially like to recognize the members of the steering committee for their guidance in structuring the sessions and for recommending the authorities to be invited as speakers.

Charles T. Cushwa	Forest Service
Raymond Corning	Bureau of Land Management
L. Lee Purkeson	National Park Service
Robert Schueler	National Marine Fisheries Service
Carl H. Thomas	Soil Conservation Service
William Davis	Environmental Protection Agency
Paul Risser	National Science Foundation
Donald Beem	American Institute of Biological Sciences
Laurence R. Jahn	Wildlife Management Institute
Norville Prosser	Sport Fishing Institute
John S. Gottschalk	International Association of Fish and Wildlife Agencies

I would also like to express my appreciation to the Chairmen of the various sessions, and to the participants.

It was our original intent to include the comments and discussions generated during the sessions in the Proceedings. However, the scope and volume of these discussions far exceed our expectations and would have necessitated doubling the size of this volume. Recognizing that much provocative material was contained in the discussion, but recognizing as well the logistical and budgetary constraints involved in assuring accuracy and attribution, I chose not to include the partial transcript of those discussions in this volume.

The Fish and Wildlife Service continues to work towards the establishment of a common framework in which information and understanding of fish and wildlife resources can be exchanged. This is a rapidly evolving field; these Proceedings reflect an instant in a dynamic continuum. Many of the promising directions reported here will have changed in the intervening period between presentation and publication.

The Fish and Wildlife Service formed the National Habitat Assessment Group in 1976 to coordinate our efforts in habitat classification and analysis. The Group has established liaison with the Forest Service, Bureau of Land Management, the new Heritage Conservation and Recreation Service, Soil Conservation Service, and other groups and agencies. Progress is being made on common systems for classifying, inventorying, and analyzing this country's natural systems on which our fish and wildlife resources, and indeed, all of us, are dependent.

Allan Marmelstein
Office of Biological Services
U.S. Fish and Wildlife Service
June, 1978

WELCOMING ADDRESS

Lynn Greenwalt
Director, U.S. Fish and Wildlife Service
Department of the Interior

Thank you very much. I welcome all of you to a symposium sponsored by the Fish and Wildlife Service and other agencies concerned with the environment and the way environmental problems are approached. I regard the symposium as a landmark of its kind; it represents the approaching of an opportunity to deal with issues that have confronted us for a long time and that have really not been fully and, perhaps, properly addressed until now.

This meeting is based on the premise that all of us must and do recognize that nothing in the environment can be dealt with in isolation. The things with which we are concerned, fish and wildlife and the places in which they live, and associated environmental factors, are closely interrelated. They form a complex web that cannot be ignored. The biosphere as we know it is a thing that encompasses considerations far beyond the realm of the heretofore traditionally geographic or political-geographic realm.

I suggest to you, also, that today it is important to understand even in the political realm, that nothing can be done in isolation. The formulation of a cartel of energy resources in the Middle East can have a profound effect on the rest of the world, as you all know. The presidential election in the United States has far-reaching impact throughout the world. The effects of an oil spill in North America can be felt, perhaps, on another continent. We understand these things are interrelated and cannot properly be considered separately.

It is important, as we address the kinds of problems that are coming to the fore, that we recognize the common goal that the varying pressures at play--exploitation, preservation, or conservation--have: the quality of life, for now and in the future. We must recognize as well, that built into this amalgam of things that confront us is the rather fundamental issue of fish and wildlife and their habitats. This is the common denominator, perhaps, that draws people's interests together; to be concerned about, interested in, and worried about future decisions that may relate to the whole of the environment. Fish and wildlife is a factor that is common to all interests and understandings.

And it is important that we, as leaders and stewards in this field, address fish and wildlife problems in the most objective, the most innovative, and imaginative way possible. This symposium is a first step in that direction. We all understand that each of us, whatever our role in the environmental world may be, is constantly confronted with the need to provide information, to gather data, to assess it, to analyze the impacts of changes in the landscape, and how they may affect the continued well-being of fish and wildlife. I think it is important now that we begin to try to speak a common language in dealing with the fundamental issues that make up fish and wildlife management resource considerations, and the classification, inventory, and analysis of fish and wildlife habitats. That is why the groups which are cosponsoring this symposium have asked you to come together to talk about ways in which we can arrive at a common approach, a common effort to the solution of the problems that are confronting us now. None of us has to be reminded that now is the time that we must address these problems as professionals and in a professional way.

I see this symposium as the opportunity to begin to do that in a very special and effective way. If we are successful, it will be possible to utilize our collective resources in a more efficient and more effective way, providing the greatest benefit possible to the resource, for which we are all responsible. I challenge you, then, to look positively at the opportunities that this symposium presents for us. You have awaiting you an impressive array of speakers, men and women who have been thoughtful on this subject, whose ideas are worth listening to. I suggest that the fundamental challenge of this symposium is to do something about it.

Now is the time for us as professionals to decide how we are going to treat these problems in the future. One of the best ways to begin, it seems to me, is to decide collectively how we are going to do this. It is not easy to arrive at a common language, or even a common understanding of what the language means. It is easier to agree that we will strive to reach such an understanding in order to work together, to employ all our resources and all our interests to a common end. It is abundantly clear to all of you that there is more to be done than all of us together can really do well. It behooves us to use our best talents, our most imaginative thinking, in order to cope with the problems that confront us, because time is not on our side. Now is the time that we must begin to do this in a really concerted, effective sort of way. With that in mind, I commend to you the subject matter that will come to you in the next several days.

The Fish and Wildlife Service, as a National organization responsible in a variety of ways for fish and wildlife and their habitats, is committed to the idea of pursuing broad ecosystem understandings from which can be derived broad ecosystem management schemes and recommendations for the use of this Nation's resources. It is important, therefore, that all of us begin to think of the challenge ahead of us in these terms. This represents, a golden and perhaps unrepeatable, opportunity to do this work. I am immensely pleased that my organization has been able to be a part of this. You will find that Allan Marmelstein and his people have done a remarkable job in arraying kinds of talent that are necessary to provoke your thinking, to enable you to join with us in an effort that is imperative if we are to realize our aspirations, as a Nation, for future generations.

Once again, let me welcome you in behalf of the Fish and Wildlife Service, to this very special symposium, and to assure you that you have the full support and the full commitment of the Fish and Wildlife Service in this endeavor.

Section I
User Manual

HABITAT DATA NEEDS FOR MANAGING WILDLIFE

Laurence R. Jahn, Vice President
Wildlife Management Institute
Washington, D.C. 20005

Abstract: The size, distribution, and variety of fish and wildlife populations are linked inextricably to the amount, diversity, and quality of available habitat. Fish and Wildlife management, therefore, is predicated on systematic accumulation and analyses of habitat data. Economic rather than ecological considerations dictated land and water uses in North America until a score or less years ago. Since then, legislation, improved resource management technology, and increased public understanding of and appreciation for ecological relationships have begun to place resource-use decisions in a more realistic perspective. Today, a four-step system--identification, delineation, maintenance, and management--should be used in resource planning and evaluation to perpetuate critical areas and habitats essential to the well-being of populations of all fish and wildlife species. The conceptual groundwork has been laid for accommodating fish and wildlife in resource decisions and allocations. More habitat prescriptions for individual as well as groups of species, and uniform use of the four-step system at all levels of government and within the private sector, are now needed.

It is a pleasure to participate in this important meeting to define more clearly the data required to effectively maintain and manage fish and wildlife populations.

My purpose is: (1) to provide some overall views on the needs for habitat information, and (2) to identify precisely types of habitat data required to perpetuate fish and wildlife populations in selected resource management situations.

In past years, decisions on use of the landscape were based largely on economic rather than ecological concerns. Recently, there has been growing recognition that decisions affecting the values and uses of the resource base, and predicated solely on economic grounds, are shortsighted and inadequate. Important ecological and social values beyond dollar expression were ignored. This void in authorities and procedures has prompted new laws, policies, and guidelines--especially within the past 10-15 years--to encompass the full spectrum of resource values.

These new laws policies and guidelines include the following:

1. Fish and Wildlife Coordination Act (16 U.S.C. 661-666c, 1934 as amended). It seeks to protect fish and wildlife habitats by requiring the U.S. Fish and Wildlife Service and the National Marine Fisheries Service to review and report on proposed water and associated land development projects. Evaluations cover projects receiving Federal funds and those permitted under Sections 9 and 10 of the River and Harbor Act of 1899, Sections 402 and 404 of the Federal Water Pollution Control Act amendments of 1972, and other appropriate Acts.

2. Bald Eagle Act of 1940 (16 U.S.C. 668-668d). It calls for protection of bald (Haliaeetus leucocephalus) and golden eagles (Aquila chrysoetos).

3. Multiple Use and Sustained Yield Act of 1960 (P.L. 86-517). It directs the U.S. Forest Service to consider all renewable resources in conjunction with one another.

4. Environmental Policy Act of 1969 (P.L. 91-190). It encourages productive harmony among man and his environment. It requires any Federally financed project be evaluated and environmental impacts, including those on fish and wildlife, and alternative opportunities be identified.

5. Coastal Zone Management Act of 1972 (P.L. 92-583). It requires States to designate "areas of land and water of particular concern" within the coastal zone for special management consideration, such as essential habitats for living resources or areas of high productivity. These include fish, shellfish, wildlife, and the food organisms and other living components of their supporting habitats. After these "critical areas" are designated, States are required to provide policies and actions to manage them.

6. Fishery Conservation and Management Act of 1976 (P.L. 94-265). It is designed to conserve and manage U.S. fishing resources within the 200-mile (322 km) fishery conservation zone, and beyond 200 miles for anadromous species and continental shelf fishery resources. Management plans are to be developed for fish populations and the habitats required to sustain them.

7. Endangered Species Act of 1973 (P.L. 93-205). It calls for conservation of endangered and threatened species, and of the ecosystems supporting them. Critical habitats required to assure survival and restoration of endangered species are identified, delineated, and maintained.

8. Sikes Act of 1974 (P.L. 93-452). It calls for new directions and cooperation with the States in planning and management of wildlife habitat on Federal lands.

9. Forest and Rangeland Renewable Resources Planning Act of 1974 (P.L. 93-378). It directs the U.S. Forest Service to inventory natural resources in the National Forest System and provide comprehensive plans for their management.

10. Federal Land Policy and Management Act of 1976 (P.L. 94-579). It establishes national policy to retain rather than dispose of the National Resource Lands, and directs that those lands be inventoried, uses be planned on a multiple-use and sustained-yield basis, and that lands be managed on a sound ecological basis, with habitat provided for fish and wildlife. Land-use plans and regulations must include protection of public land areas of critical environmental concern. This means delineated areas of public lands where special management attention is required, among a broad spectrum of purposes, to protect and prevent irreparable damage to important fish and wildlife resources or other natural systems or processes. In resource inventories, priority shall be given to designation and protection of areas of critical environmental concern.

Many of these Federal laws, as well as similar State laws, call for identification, delineation, maintenance, and management of critical areas required to sustain fish and wildlife populations. Although the broad scope of the accumulating laws is of recent origin, the procedures are not. They have proven sound, practical, and useful over several decades in a number of management efforts, particularly for anadromous fish and such migratory birds as the whooping crane (Grus americana).

Canada protects the crane's breeding habitat in Wood Buffalo National Park, U.S. State and Federal agencies protect the birds and areas used during migration, and the Aransas National Wildlife Refuge assures availability of the primary wintering habitat. Broad horizons are required to encompass all seasonal habitats used annually by the cranes.

Ecological patterning of critical areas, to maintain seasonal habitats of designated populations of fish and wildlife species, needs to be applied in many more cases. It requires combining specific information on populations, with data on important habitats throughout their annual ranges, to permit delineation of critical areas of the landscape important to individual species or groups of species.

It should be obvious that the four-step system (identification, delineation, maintenance, and management) to handle critical areas has the unique capability of accommodating essential populations and habitat data at different levels of refinement. The grizzly bear (Ursus arctos horribilis) and its habitat provide an example. In the absence of precise knowledge of what constitutes "critical habitat" for the grizzly, the Federal government recently delineated some large "critical areas" and announced them in the Federal Register. Some people believe it is best to use this broad area approach now and later, from research findings, precisely define, within the delineated area or areas, what is grizzly bear critical habitat, where it is located, and what modifications of the landscape have adverse or beneficial impacts. This evaluation and further definition will require time for study. But, prompt delineation of the general areas occupied by remnant grizzly populations alerts everyone in those areas that grizzlies are to receive special consideration there. Exactly what is to be done to benefit the bear populations remains to be described in the management plan for each designated population. Some critical elements that deserve special attention, according to Charles Jonkel, the respected bear researcher now in Montana, include: early spring feeding sites; denning sites; local sites devoid of human disturbance; and sites where bears do not now conflict with livestock or other human activities for space and resources.

This approach of defining critical areas and subsequently identifying critical habitat elements within those delineated areas needs to be applied more frequently, in order to help assure maintenance of existing fish and wildlife populations, as man's activities modify the landscape. We must develop resource management plans, based on scientific and social facts, that are sensitive to the habitat needs of fish and wildlife. Such plans require working at a refined level of discrimination in habitat inventories and management efforts, such as focusing on individual nesting trees used by pairs of bald eagles.

In the Chippewa National Forest in Minnesota, biologist John Mathisen has prepared individual management plans for approximately 100 bald eagle territories. The tree supporting the nest is the central focus, with surrounding roosting trees and feeding habitat rounding out this critical, seasonal area. Timber harvesting and regeneration activities are designed to prevent disturbance of the eagles during the nesting season and to perpetuate essential breeding habitat. Individual trees now accommodating breeders or with potential as nesting sites are marked to avoid their being cut down. Timber-management activities, including harvesting, are scheduled between 1 October and 15 February to minimize disturbance when breeding eagles are present. Likewise, certain roads and trails within specified distances of trees supporting nests are closed to travel for prescribed periods of time. Aerial photographs taken at altitudes of 100 to 300 feet (30 to 91 m) are the basic illustration in the management plan for use by field foresters. Overall, foresters have readily accepted and implemented these eagle management plans.

The latter Minnesota example illustrates the refinement required to meet legal demands of the 1940 Act to protect the bald eagle during the nesting season. Obviously, similar approaches are needed to assure availability of critical areas and specific habitats used by bald eagles in other geographic locations and seasons. With wide-ranging species, our framework for sound management of populations must encompass all habitats used throughout the year.

Prescriptions are needed to modify standard silvicultural practices to maintain designated fish and wildlife populations. These modifications require identification of vegetative types, ages, and disperson within forest management compartments, each roughly 1,000 acres (405 ha) in size. It is at this early stage of planning that fish and wildlife habitat needs are incorporated or left out. For some species, such as the spotted owl (Strix occidentalis) that requires stubs of old trees for nesting sites, foresters are asked to recognize newly identified values of snags. Classification and inventory procedures must record snags to be of value to foresters and other resource managers responsible for perpetuating nesting sites for the spotted owl in the Pacific Northwest. Jack Ward Thomas describes in this Proceedings an important new system for assuring maintenance of wildlife habitat in forest management plans.

A similar detailed set of characteristics is needed on aquatic areas to permit judging the capabilities of these areas for accommodating a variety of organisms, including fishes. Norville Prosser and his associates at the Sport Fishing Institute prepared an outline of habitat data needs for managing fisheries (Appendix A). This outline focuses on the physical, chemical, biological, and social characteristics that are needed to frame managment plans for streams, rivers, ponds, lakes, and reservoirs. Topographic maps with contours of 2 to 5 feet (0.6 to 1.5 m) would be most helpful, especially when combined with measurements of critical items such as seasonal flow patterns, physical developments installed on aquatic areas, and special features such as springs, riffles, and aquatic vegetation. Two important points are evident for fish, as well as for other species: (1) general habitat inventory data are useful in delineating areas of importance, and (2) inventory data must be available in considerable detail to delineate critical habitats for management to benefit a species as well as groups of fish and wildlife species.

The term critical area is being used to encompass a broad spectrum of fish and wildlife values, as well as other important public values associated with aquatic areas. These public values include water retention for flood prevention, groundwater recharge, nutrient cycling and water purification. Because of the full spectrum of public values involved, State and Federal laws and policies now require that aquatic areas be given special attention and man's activities be guided to prevent degradation and destruction. This legal requirement created a demand for results from the pending national wetland inventory. Information from this inventory can be helpful to a variety of users, assuming it is readily available to field personnel in sufficient detail and in the form needed for management. All 20 or more types of wetlands discussed later in these Proceedings by Lewis Cowardin should be included down to a fraction of 1 acre (0.4 ha).

Detailed information on habitat types is required to permit agencies and organizations to complete more adequate environmental assessments and impact statements on proposed development projects. Intensive evaluation of pre- and post-construction data on Bureau of Reclamation and Corps of Engineers projects emphasizes the need to upgrade the inventory of landscapes within proposed projects to: (1) document more precisely the pre-construction types of habitat, (2) delineate important existing fish and wildlife habitats, such as wetlands, and (3) to maintain those critical areas and habitats that are delineated. The record shows that pre- and post-construction resource inventories, plans, and evaluations of proposed development projects have been less than adequate. The important challenge is for teams of well-qualified, multidiscipline-resource researchers and managers to complete more careful pre-construction evaluations that clearly identify realistic alternatives which fully encompass the reproduction and survival needs of fish and wildlife. Everyone participating in proposed projects should become involved at the earliest stages of planning. Plans for each project should be framed on the basis of the four-step system described earlier: identification, delineation, maintenance, and management of critical areas and habitats required to sustain fish and wildlife populations.

That system should be used in developing plans for all aquatic areas, rangelands, pasturelands, croplands, woodlands, urban-suburban areas, and other units of the landscape. The system will require habitat data of several degrees of refinement to design multiple-benefit plans that include fish and wildlife values. If hopes are realized the speakers at this Symposium will help define the specific levels of refinement required for specific situations.

APPENDIX A

HABITAT DATA NEEDS FOR MANAGING FISHERIES

Norville S. Prosser
Sport Fishing Institute
Washington, D.C.

I Physical Descriptors to be delineated on appropriately scaled maps

A. Stream/river fisheries

1. Area and length

- pool habitat
- riffle habitat
- cover
- gradient

2. Flow (seasonal values)

- volume: maximum, minimum, averages
- temperature: maximum, minimum, averages
- velocity

3. Developments

- dams, impoundments, and diversions
- bridges
- access
- channeled or altered sections

4. Special habitat

- spawning areas (anadromous also)
- rare and endangered species habitat
- springs

5. Watershed characteristics

- area
- runoff patterns
- vegetative cover
- sources of noxious or toxic materials

B. Lake/reservoir fisheries

1. Basin

- surface area: normal pool, minimum pool, flood pool
- depth profiles, considering expected pool elevational changes
- temperature profiles (monthly)
- turnover or flow-through rate
- location and extent of standing timber

2. Shoreline

- length
- configuration (shoreline development)
- erosive characteristics
- extent of riprapping

3. Development features

- access and parking facilities
- lake and shoreline zoning plan
- fish passage facilities
- artificial piers, fish attractors including special consideration of tailrace
- seining and/or netting areas

4. Watershed characteristics

- area
- runoff patterns
- vegetative cover
- sources of noxious or toxic materials

II Chemical Descriptors

A. Natural or background elements

1. alkalinity

2. conductivity

3. pH

4. key elemental levels: N, P, K, S, and others

B. Pollutants or introduced elements

1. suspended sediments

2. noxious or toxic substances including dissolved gases

III Biological Descriptors

A. Resident community

1. Species composition

- animal (vertebrate & invertebrate)
- plant

2. Standing crops

- game species
- nongame species

B. Special Uses

1. Migratory fishes

- species
- abundance

2. Rare or endangered species

- species
- abundance

IV Social Descriptors

A. Index of uniqueness of subject habitat: considers habitat type, quantity, quality, present and projected user demand

1. local

2. State

3. regional and perhaps national

B. Estimated use of and yield from habitat (present and projected)

1. Consumptive use

- recreational
- commercial

2. Non-consumptive use

- competing (boating, skiing, etc.)
- non-competing (outdoor classroom study, etc.)

MANY USES AND MANY USERS: SOME DESIRABLE CHARACTERISTICS OF A COMMON LAND AND WATER CLASSIFICATION SYSTEM

Lawrence S. Davis
Professor of Forest Economics
Department of Forestry and Outdoor Recreation
Utah State University
Logan, Utah 84321

Jan A. Henderson
Assistant Professor of Forest Ecology
Department of Forestry and Outdoor Recreation
Utah State University, UMC 52
Logan, Utah 84322

Abstract: A cost-effective land and water classification system must be designed and implemented to satisfy the particular needs of each user. There are many needs for classification and thus many different classification systems. Substantial efficiencies along with improved communication can be achieved, however, by building these different classification systems from a common conceptual and procedural framework.

The central objective in this paper is to specify the structure of this common framework for classification. First we will examine the different clientele and the uses they make of land and water classification. Next the functional role of classification will be formally established within a model of solving problems in resource management by using a classification-based information system. Given these uses and this functional role of classification, we then review the three basic approaches to classification--component, integration, and regionalization--and present a classification of classification systems. The paper is summarized by listing elements of a common classification framework and recommendations for building efficient systems from this framework.

The ideas and material presented here reflect the contributions of over 30 staff and graduate students working on a research project sponsored by the U.S. Forest Service UFS-SEAM Program of the Intermountain Forest and Range Experiment Station.

CLIENTELE AND USERS

The practicality of land and water classification is tested at the forest or field level of program implementation. It is here that treatments are executed, results observed, and we see how well predicted responses match reality.

Classification has several important roles at the local level. It serves as (1) a basis for inventorying the status of current resources, (2) a means of transferring experience and knowledge of a studied area to a similar but unstudied area, (3) a framework for assessing local management opportunities and predicting the outcomes of treatments or actions, and (4) a vocabulary for communication between manager and managers, manager and researchers, and between managers and the public.

These roles of communication will be examined from the perspective of five kinds of users at the field management level. For each kind of user, we will review the types of information needed, the uses to be made of land and water classification, and consequent desired characteristics of classification systems.

THE MANAGER-DECISIONMAKER

The manager has to choose among alternative solutions to problems ... problems which range from long-range, land use plans to an on-site decision whether to cut a particular tree. For the accountable decisionmaker, land classification has particularly important roles: (1) as the scientific basis of his information system and (2) as a language for explaining how or why certain consequences are expected and specific choices are made.

For the first role, the manager wants to know that the classification and information system used in the decisionmaking process is professionally credible. Technical or scientific soundness is the basis of such credibility and this in turn means the system has to be (1) conceptually accepted by peer review, (2) capable of objective validation and, preferably, (3) validated.

The importance of the second role has increased as managers of public and private forest spend a greater percentage of their time explaining and justifying their expectations and actions to critical, but not technically expert people, whether concerned citizens or high level administrators. To be useful as a communication device the classification should have a simple, common sense logic and vocabulary. Classification and interpretation of a given project site are frequently demonstrated in the field. When the classification system is based on site characteristics that can be seen and measured, the system and interpretation are more likely to be understood and accepted.

ADMINISTRATIVE STAFF

Budget preparation and program implementation require that land or water areas be grouped by strata of relatively homogeneous treatment response. Classification is the technique of setting up such strata. If assessment of opportunities considers spatial relationships, and program implementation needs on-the-ground guidance, then the land classification should be mapped. The classification system must provide homogeneous response strata and be relatively inexpensive to map. Administrators increasingly ask cost effectiveness of classification, mapping, and related information systems because budgets are always tight.

PLANNING STAFF

For many persons, land use planning operates by visual analysis and makes extensive use of maps and map overlays. To make a land use plan, which is largely the business of deciding which tracts of land and water to allocate or use for different purposes, the area in question must be disaggregated geographically into many small land parcels for which uniform prescriptions or allocations are made. Classification serves as the basis for delineating and mapping these parcels. The methods of delineation should be keyed to the goals of planning and selected to identify critical planning factors such as erosion, productivity, current use, or visual value. Classification needs to effectively identify and isolate such critical planning factors.

TECHNICAL SPECIALISTS

One of the key functions of staff specialists such as silviculturists, hydrologists, engineers, or wildlife biologists, is to make on-site analyses and evaluations of specific projects (such as an environmental impact statement) and recommend a prescription for project implementation (for example, a silvicultural prescription, a drainage plan, or a road specification).

To make these evaluations and prescriptions the technical specialist needs a great deal of specific information: soil depth, infiltration rate, tree productivity, probability of successful natural regeneration, wildlife habitat suitability, and much more. Much of this sort of information is either too expensive to measure directly or is simply unknown for the site in question. The specialist, to obtain the information, relies partly on primary data and published research results but very heavily on judgment and experience gained elsewhere. The key to transferring the experience gained elsewhere, to the project site in question, is to accurately identify the "kind of place" or "environment" of the site and look for experience on similar kinds of places elsewhere.

The classification system serves to identify and label "kinds of places." To do this efficiently the methods of labeling need to be objective, well documented, and available to the average technical staff. Moreover the classification needs to provide several options about how places can be identified depending on skills and resources available.

INFORMATION SYSTEM STAFF

Land and water classification per se provide very little information and the relationship of the different land classes to specific response information (such as growth and yield) needs to be established. It is unlikely that research organizations of government, industry, and the universities will ever have the resources to develop and communicate the extensive empirical information needed by management. The line organizations will have to collaborate with research if this information is to be available.

But this is not as difficult as it might seem. Every harvested forest stand, road built, site prepared, fishery stocked, or campground provided can be viewed as an experiment. All we need to do is describe the environmental conditions and the treatment, observe what happens, and compile the results from such "applied" experiments to build an information system. Much of this we already do in the planning process.

In land classification we describe the environmental conditions (kinds of places) and build the basic labeling system for filing data on cases and experiments for future retrieval. The function of the information system staff (supplying information) is the direct counterpart to the planning and technical staff (using or demanding information), with the land classification system being the vehicle for information transfer, storage, and retrieval. The land description system is then an important bridge between research and application.

USER REQUIREMENTS OF CLASSIFICATION SYSTEMS

The "multiple" uses and users of land and water classification indicate diverse requirements. As we move to the State, regional, and national level of users the focus shifts from program and prescription to assessment and policy direction. New requirements are that (1) the classification and information system provide comparable data for regional and national aggregation for assessment and planning and for the subsequent disaggregation of the budgets and programs of the selected policy option, and (2) that the classification be flexible enough to allow some tradeoff between accuracy and the cost of information.

Many different governmental units and executive agencies make use of classification systems. Furthermore, legislation such as the Resources Planning Act of 1974, as amended by the National Forest Management Act of 1976, states that one agency (in this case, the Forest Service) is supposed to aggregate land and water data from several other agencies to carry out the mandate of the legislation (exactly how this was to be done was not clear in the legislation). This implies that the different agencies should adopt a common approach to their classification and information gathering.

In summary, user requirements of classification systems are that:

1. The system be professionally credible based on conceptual and empirical validation.

2. The system have a straight-forward logic and language suitable for communication with the nontechnical.

3. The system be sufficiently diverse or flexible to provide homogeneous strata for predicting a wide range of information.

4. The logic and structure of the system be suitable for building and operating a comprehensive, computer-based management information system.

5. The system permit regular professional staff, with nominal training, to use the system to map, identify, and classify project sites.

6. The system be useful to most major governmental and private groups needing classification and information systems for land and water resources.

7. The system be demonstrably cost-effective.

So the question before us is "To what extent can the same or common environmental classification system meet all these needs: if so, what are the common aspects?"

Intuitively, the idea of a common system is appealing. Effectiveness is better because we can pool data and share information among more users; thus each user has more information. Cost efficiency is improved because each piece of data is used more often, lowering unit cost, and each user does not have to start from scratch and incur the relatively large fixed costs of designing and setting up a system. Finally, it is easier to communicate and we can get on with solving problems and spend less time translating language differences.

To explore the question "What are the common properties of a 'multiple-use environmental classification system'", we need to look more carefully at the concept of classification. We have said the primary reason for classification is to obtain information which helps us to deal with our problems. Furthermore, classification is the cheapest way to access needed information. As a labeling and stratification approach, classification makes response information available from research and makes experience gained elsewhere transferable. Generalizing information that has already been gathered or recorded is considerably cheaper than gathering primary data for each case.

A MODEL OF PROBLEM SOLVING IN RESOURCE MANAGEMENT USING A CLASSIFICATION BASED INFORMATION SYSTEM

Thus far the basic theme that classification is a means for compiling and providing information to managers and planners has been developed informally. It is useful now to define this idea about classification more formally in the context of a management information system for problem solving in resource management.

Such a system has three major elements (Figure 1); the first element is managerial problem solving and includes problem perception, identification, analysis, and solution. One result of these activities is specification of information needed to solve problems. These information needs can be divided into socioeconomic (prices, costs, value, employment, etc.) and biophysical (productivity, habitat quality, erosion potential, etc.) categories.

A second element is the data base in the information sytem. For the moment this can be visualized as maps, tabular data, books, libraries, experts, and other material which may contain the information specified in problem analysis.

The third element of the system is the procedure for accessing the information. This is the mental, manual, and computerized technology by which the information data base is searched and needed information items are retrieved and delivered in the desired format to the managers and other problem solvers.

Problem identification and analysis can be expanded further (Figure 2). Problems (P) are usually perceived as fairly complex or broad issues. For example: "What bag and season limits will we place on waterfowl this year?" or "What is the potential for producing more red meat on Bureau of Land Management (BLM) lands in New Mexico next year?" or "Is it safe to put a road up this canyon?" Each of these problems, when subjected to thorough problem analysis, results in several to hundreds of specific questions (Q) which must be answered in order to solve the problem. Examples of questions would be "What is the current and potential forage productivity of BLM lands? What are the costs of treatments? What is the system access to BLM land? What will be the impact on big game forage of intensified domestic livestock activity?"

The distinction between problems and questions is only a matter of degree. Depending on the initial problem, several intermediate stages of question analysis are possible. One result of question analysis is fairly specific however: it is two lists of information (I_S, I_B) specified in units and format which are needed to answer the questions and solve the problems.

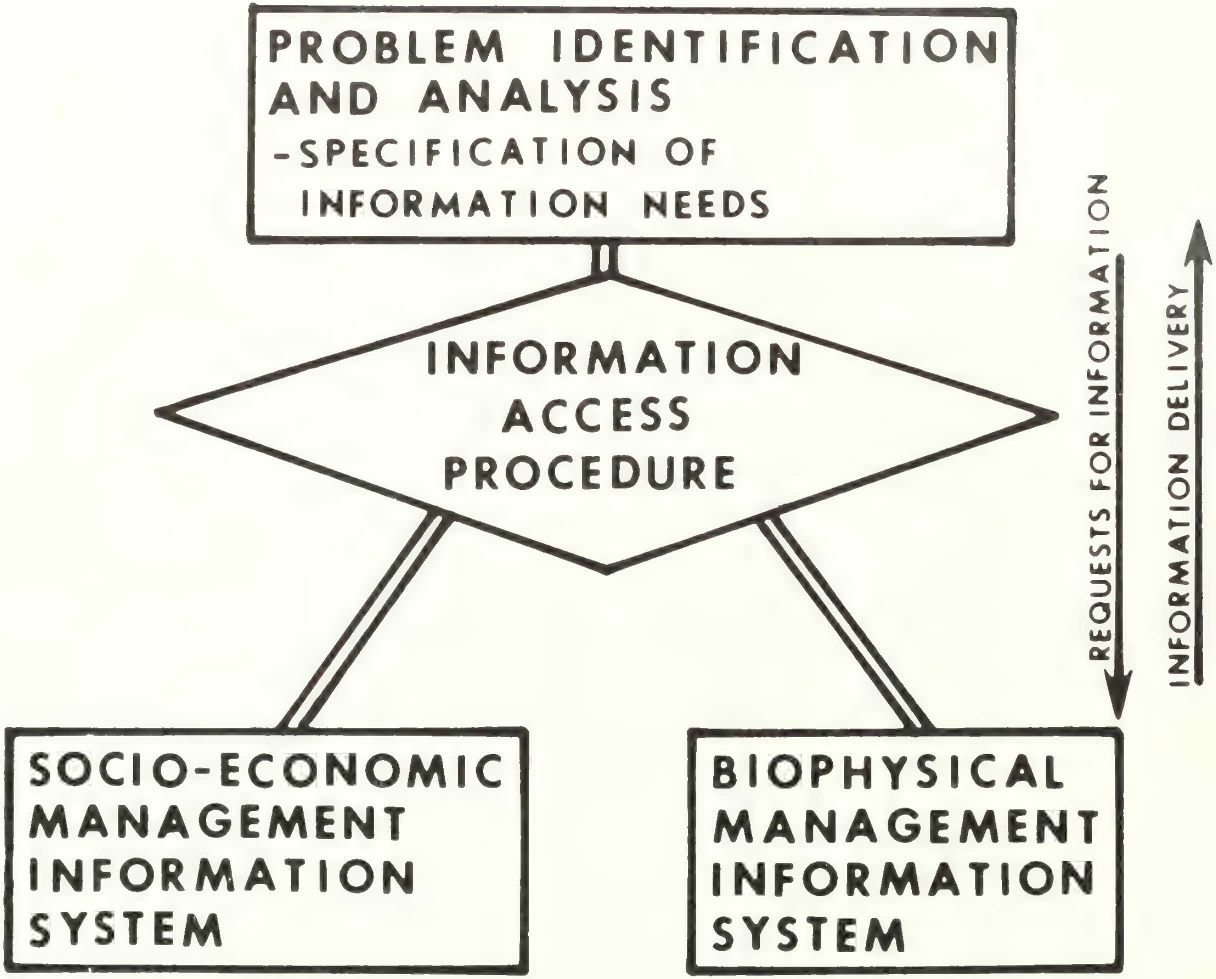

PROBLEM IDENTIFICATION AND ANALYSIS
-SPECIFICATION OF INFORMATION NEEDS
INFORMATION ACCESS PROCEDURE
REQUESTS FOR INFORMATION
INFORMATION DELIVERY
SOCIO-ECONOMIC MANAGEMENT INFORMATION SYSTEM
BIOPHYSICAL MANAGEMENT INFORMATION SYSTEM

Figure 1. Major elements of problem solving.

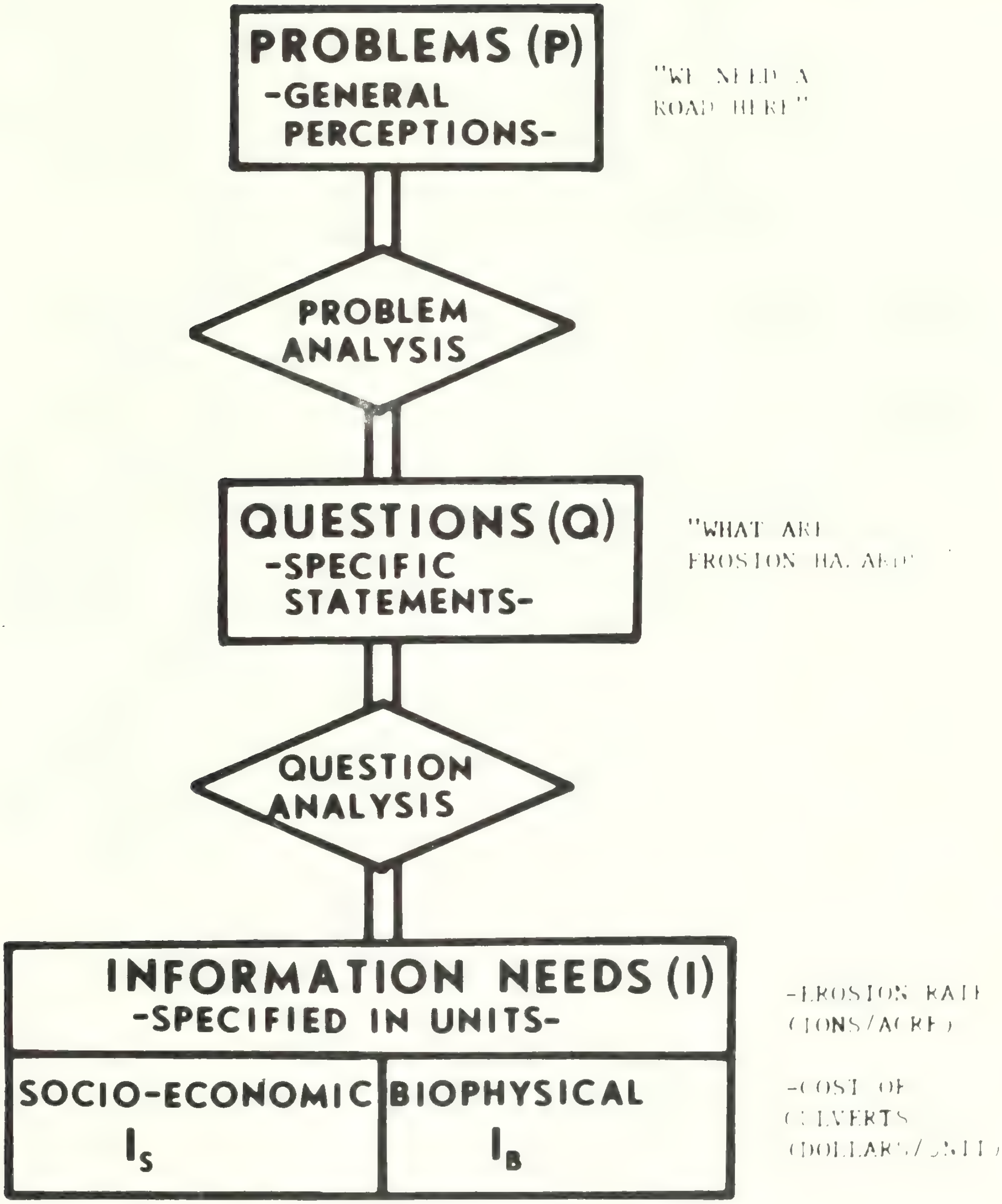


Figure 2. Problem identification and analysis.

To summarize, we start with a statement of the problem and end up with lists of specific information. Between the statement and the list lie most of the methods and subjects of economics, management science, and other social sciences. Benefit/cost analysis, linear programming, supply and demand models, and program budgeting are all analytical tools of problem or question analysis.

The next step is to obtain the specified information from somewhere. We will set aside detailed consideration of the socioeconomic list (I_S) by saying there is a source somewhere (Bureau of Labor Statistics, Census, Commerce, and various others) and put our attention on the biophysical information sources. It is important to remember, however, that to answer questions and solve problems, socioeconomic information is invariably needed!

An expanded outline (Figure 3) of the biophysical information system shows the environmental classifications (E) being used as the independent variables or strata to predict a wide variety of elementary and complex biophysical information (X_I, X_{II}). The models or procedures for predicting are called "rules" ($X = f(E)$). Again, this is an over-simplification since information and rules come in varying degrees of complexity. An example of a simple rule might be a yield table for timber productivity (Table 1). An example of a complex rule might be a spatial search rule to specify wildlife habitat (Figure 4).

Table 1. Example of a Simple Rule[a/]: A Yield Table for Timber Productivity

Mean Annual Precipitation in inches	Wood Production in Cubic Feet per Year per Acre		
	Douglas fir (*Pseudotsuga taxifolia*)	Ponderosa Pine (*Pinus ponderosa*)	Aspen (*Populus* spp.)
15-20	20	25	
20-25	40	50	30
25-30	80	70	60
35-40	100		80

[a/] Wood production per cubic feet per year per acre is predicted by $X_1 = f\ (E)$ where E_1 is potential vegetation and E_2 is precipitation.

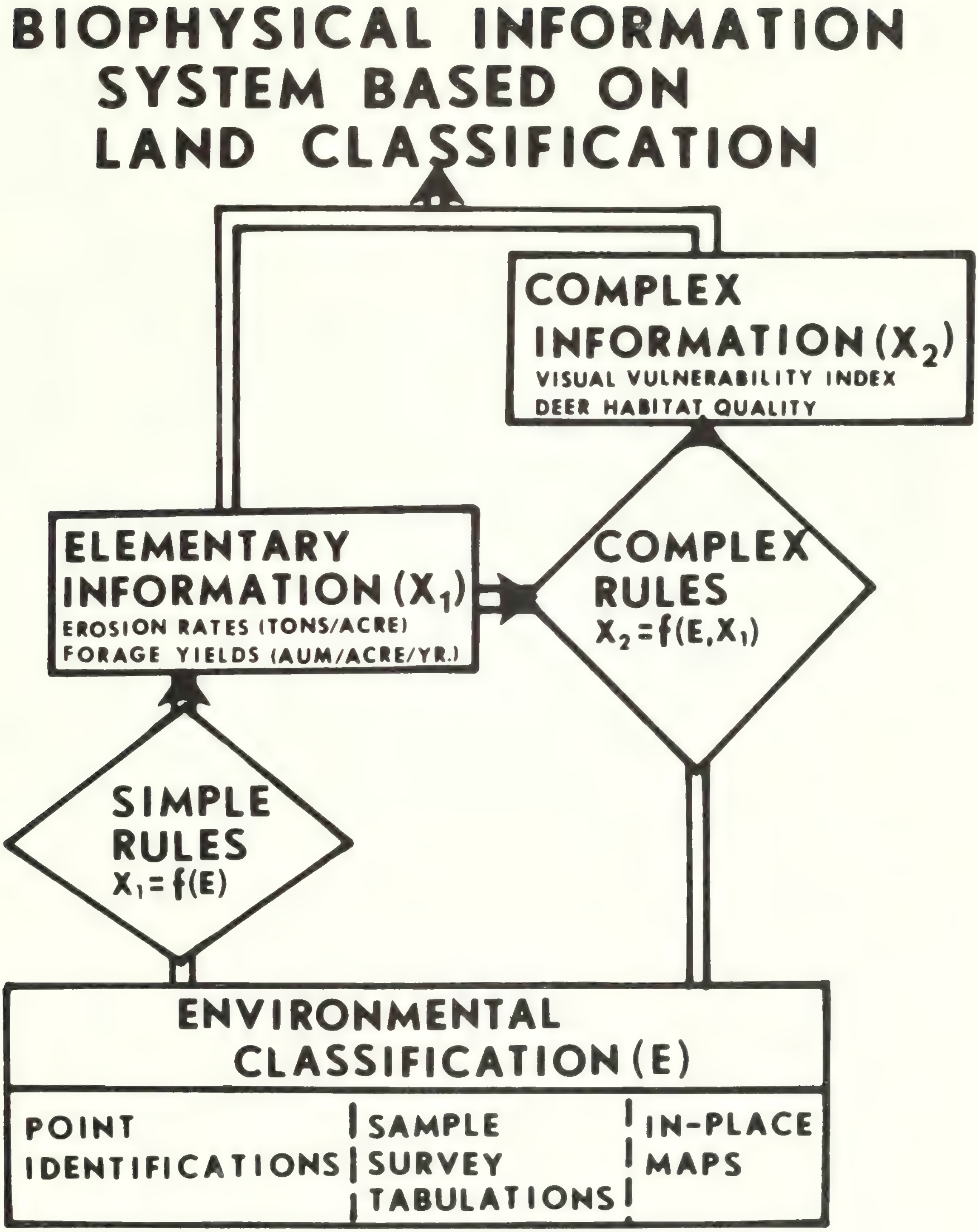

BIOPHYSICAL INFORMATION SYSTEM BASED ON LAND CLASSIFICATION
COMPLEX INFORMATION (X_2)
VISUAL VULNERABILITY INDEX
DEER HABITAT QUALITY
ELEMENTARY INFORMATION (X_1)
EROSION RATES (TONS/ACRE)
FORAGE YIELDS (AUM/ACRE/YR.)
COMPLEX RULES
$X_2 = f(E, X_1)$
SIMPLE RULES
$X_1 = f(E)$
ENVIRONMENTAL CLASSIFICATION (E)
POINT IDENTIFICATIONS
SAMPLE SURVEY TABULATIONS
IN-PLACE MAPS

Figure 3. The biophysical information system.

COMPLEX RULES
$X_2 = f(E, X_1)$

EXAMPLE: MULE DEER HABITAT
-- A HYPOTHETICAL EXAMPLE --

RULE - USING A 640△ ACRE CELL IN A GRID MAPPED DATA BASE,
A CELL IS CONSIDERED TO BE MULE DEER HABITAT (X_2)
IF, OF THE CELL OR OF THE EIGHT ADJACENT CELLS,

1. ONE CELL IS IN A TREE COMMUNITY (E_1)
2. ONE CELL HAS SURFACE WATER (E_2)
3. THE ELEVALTION OF ONE CELL IS OVER 5000' (1,524 m) (E_3)
4. THE ELEVATION OF ONE CELL IS UNDER 4000' (1,219 m) (E_3)
5. MEAN BIOMASS PRODUCTION ON ALL CELLS IS > 500 LB / ACRE 560 kg / ha (X_1)

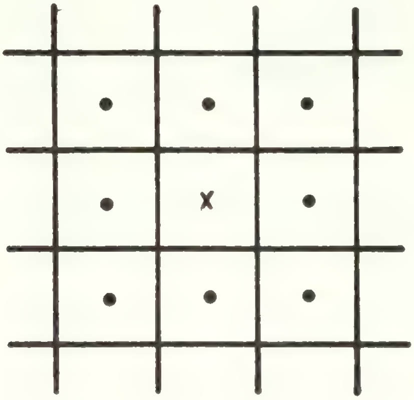


Figure 4. Complex rules - A wildlife habitat example.

Environmental classifications are used in three ways: (1) To identify particular places on the ground, (2) as strata for sample surveys, and (3) for mapping. In each application, the classifications provide data to be used in "rules" to predict desired information. Note that this is a model of an information system and that simply classifying (E), the environment, does not in itself provide information. Someone still has to quantify the rules before the system is operational. This requires research, field observation, and a careful gleaning of administrative records to measure X, E and to establish the rules (f).

A brief look at the access procedure is needed to complete our development (Figure 5). Much of the pyrotechnics, fanfare, and interest surrounding information systems has centered on the access system. Computers and elegant graphical displays hold forth and are a prominent part of access systems. The access system should be evaluated by the efficiency with which it takes a given request for information (I_S, I_B), searches the information files for the appropriate data (X_S, X_B), retrieves, transforms, and delivers it to the manager in the format needed (I_S, I_B). Development of access systems has run far ahead of careful identification of kind, format, and users of information and the structure of the information system. Because of this we are having some difficulties in getting information systems to work and the whole idea of information systems has earned a relatively "poor performance" reputation with the practitioners.

If the three elements are assembled as shown in Figure 2, the conceptual model of natural resource problem solving using an information system based on land classification is completed. This is the basic content of the recent USFS-SEAM publication, QRD: A Concept for Today...and Tomorrow. This is an excellent, popularized version of these ideas written by a professional writer. QRD stands for Questions (Q), Rules (R), Data (D), the three main items in the model. For copies write Surface Environment and Mining Program, U.S. Forest Service, 145 Grand Avenue, Billings, Montana.

Given this context, our attention is again focused on the classification system (E) to see what strategies and characteristics will make it perform effectively.

COMPONENT, INTEGRATED, AND REGIONALIZED CLASSIFICATION APPROACHES

The first approach we will consider is identifying and classifying environments by factors or components. Components are the familiar biophysical aspects of bedrock, regolith, soil, climate, topography, and vegetation. Some of these components are relatively stable (bedrock) while some are much more temporal (current vegetation or animals). Human development, organization, and use of space also lends itself to component type classification (i.e., ownership, roads and structures, land use, etc.) (Table 2).

There are alternative ways to classify each of these components and there are problems in deciding the relative importance and relations of the different components. While these issues are by no means fully resolved, it should be possible at the present time to specify and agree upon a set of components which could be used to identify and classify environments. In terms

'DATA' BECOMES INFORMATION WHEN DELIVERED TO THE MANAGER

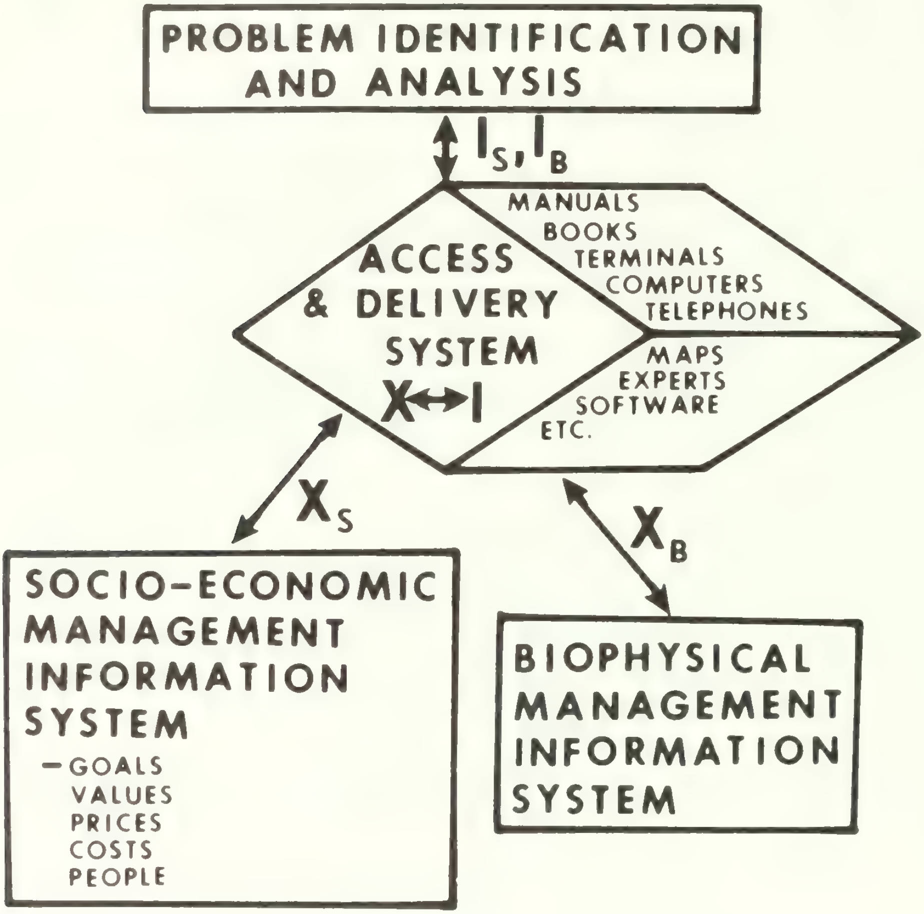


Figure 5. The access and delivery system.

Table 2. A List of Principal Measurable, Quantifiable, And/or Identifiable Biophysical Attributes of Land and Water

Land and water attributes
Permanent attributes
Bedrock
Regolith
Soil
Climate (precipitation, temperature, solar radiation)
Topography (elevation, aspect, slope)
Potential vegetation
Water (amount, size, physical and chemical composition)
Temporal attributes
Current vegetation
Current animals
Physical development (roads, buildings)
Human organization (ownership, use)

of our model, (E) becomes the set of components $e_1, e_2, \ldots, e_i$. Classification of a site becomes the assignment of a value for each of the components e_i .

Each component can be classified in a hierarchical structure because there are different levels of generalization and resolution. The structure of hierarchical classification is dendritic, where each higher level in the classification is an aggregation of those and only those classes or types in the level immediately beneath it. The class becomes more and more homogeneous as lower, finer, more detailed levels of the hierarchy are used. Classification and/or mapping are more expensive at detailed levels of the hierarchy but presumably information is more accurate due to increased homogeneity within the class; thus a tradeoff of cost and accuracy can be considered. Using the subscripts (i) to represent the actual name of a class within level and component, then a component system can be represented as e_{ijk} and shown as a matrix (Figure 6).

Components, as we have defined them, are place-independent. That is, you do not have to know where you are geographically to classify an object or a site. An approximate test of place-independence is: "If someone took a giant cookie cutter and sectioned out a half-acre or so of an environment of interest, and brought it into your classification laboratory in the Houston Astrodome, could you classify it?" Place-independence requires that the classification be determined only by characteristics that can be perceived, counted, or measured on the site being classified. Rocks or soils are good examples of place-independent environmental attributes whereas big game habitat cannot meaningfully be classified without knowing the geographic juxtaposition in time and space of a diverse set of factors relating to food, shelter, and reproduction.

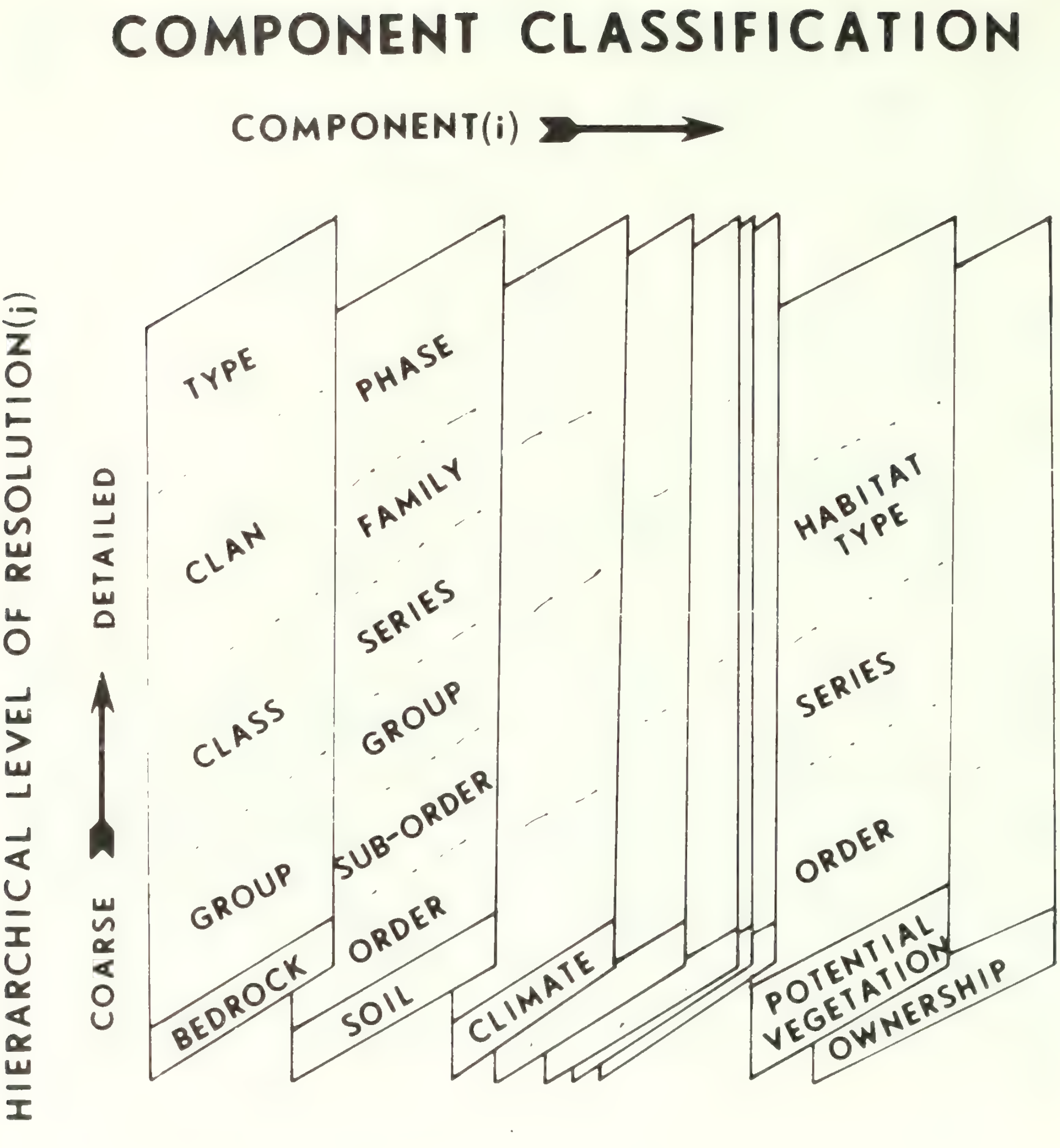


Figure 6. A component classification system.

A final feature of components is that, taken collectively, they include for each environment virtually all of the characteristics which can be seen, identified, counted, and measured.

INTEGRATED CLASSIFICATION

Integrated classification follows directly from the components and involves the permutations of two or more components (Figure 7). This can be easily visualized as the combined map produced by overlaying two or more component maps. Note that an integration really is an information rule and we classify land by the results of the rule.

Integrations, as defined here, are still place-independent since they are based strictly on the components and the rules of integration are explicitly preserved. The new classes formed by the integration may be given a new set of names, however, such as "productivity units" or "ecotypes."

REGIONALIZATION

The definition of regionalization, "Classifying and delineation of space on the basis of environmental affinities and relationships," is borrowed from a preliminary draft of Bob Bailey's Ecoregion support document. (A Regional Approach to Ecosystem Classification for Purposes of Resource Inventory--An Initial Effort by Robert G. Bailey. Mimeo-Review Draft, March 1976. USFS, R-4, Ogden, Utah.)

The defined action is delineating space (mapping). By definition then, regionalization only exists geographically as a map and cannot be place-independent. Regionalization operates by mapping rules and delineates space at one or more hierarchical levels (Figure 8). The criteria for evaluating a given regionalization are found in the purpose of mapping and the subject of evaluation is the relationship of this stated purpose to the selected mapping rules.

Regionalization is related to the component approach through the mapping rules. Mapping or space delineation has to operate on something that can be seen or measured and we have already stated that these are collectively covered by the components. Therefore, the mapping rules must be some function of the components, whether or not this "function" or mapping rule is made explicit (Figure 9).

We have many classification systems which are essentially regionalizations although very few of them are well documented and discuss the mapping rules. Because of this we cannot really discuss the logic or meaning of actual maps. Bob Bailey's Ecoregion is a notable exception. Classifications have used a wide variety of mapping rules, some hierarchical, some being used on only a few components and others on many. Many are subjectively accomplished and imply rather complex either/or choices in their rule structure.

A simple sequential mapping at three hierarchical levels based on three components is selected (Figure 10) as an example of a mapping rule and how it relates to components. In this example, the maps produced after rule 3 could also illustrate a strict integrated classification defined by the overlay of the three components $(e_{33}) \times (e_{23}) \times (e_{12})$. The difference would be the degree of smoothing and handling of inclusion in the regionalization mapping process.

RULE: IN ORDER TO IDENTIFY SITES WITH HIGH POTENTIAL FOR MASS FAILURE, CROSS-CLASSIFY BY SLOPE PERCENT (10% INTERVALS), SOIL GROUP, AND CURRENT VEGETATION SERIES AND CONDITION.

VEGETATION	SOIL SLOPE			
	A SOILS		B SOILS	
	0 - 40%	40% +	0 - 40	40+
CONIFERS	L	L	L	L
BRUSH	L	L	M	L
GRASS	L	L	H	M
BARE	M	L	H	H

HIGH = (H) = > 15% CHANCE OF FAILURE
MEDIUM = (M) = 1 - 15% " " "
LOW = (L) = < 1% " " "

MAPPED:

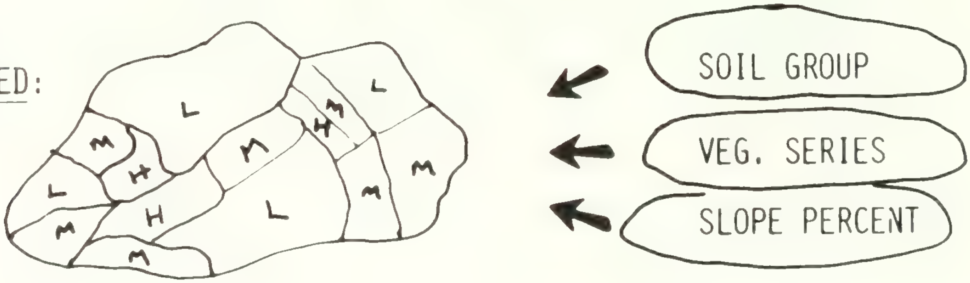


Figure 7. Integrated classifications: an example.

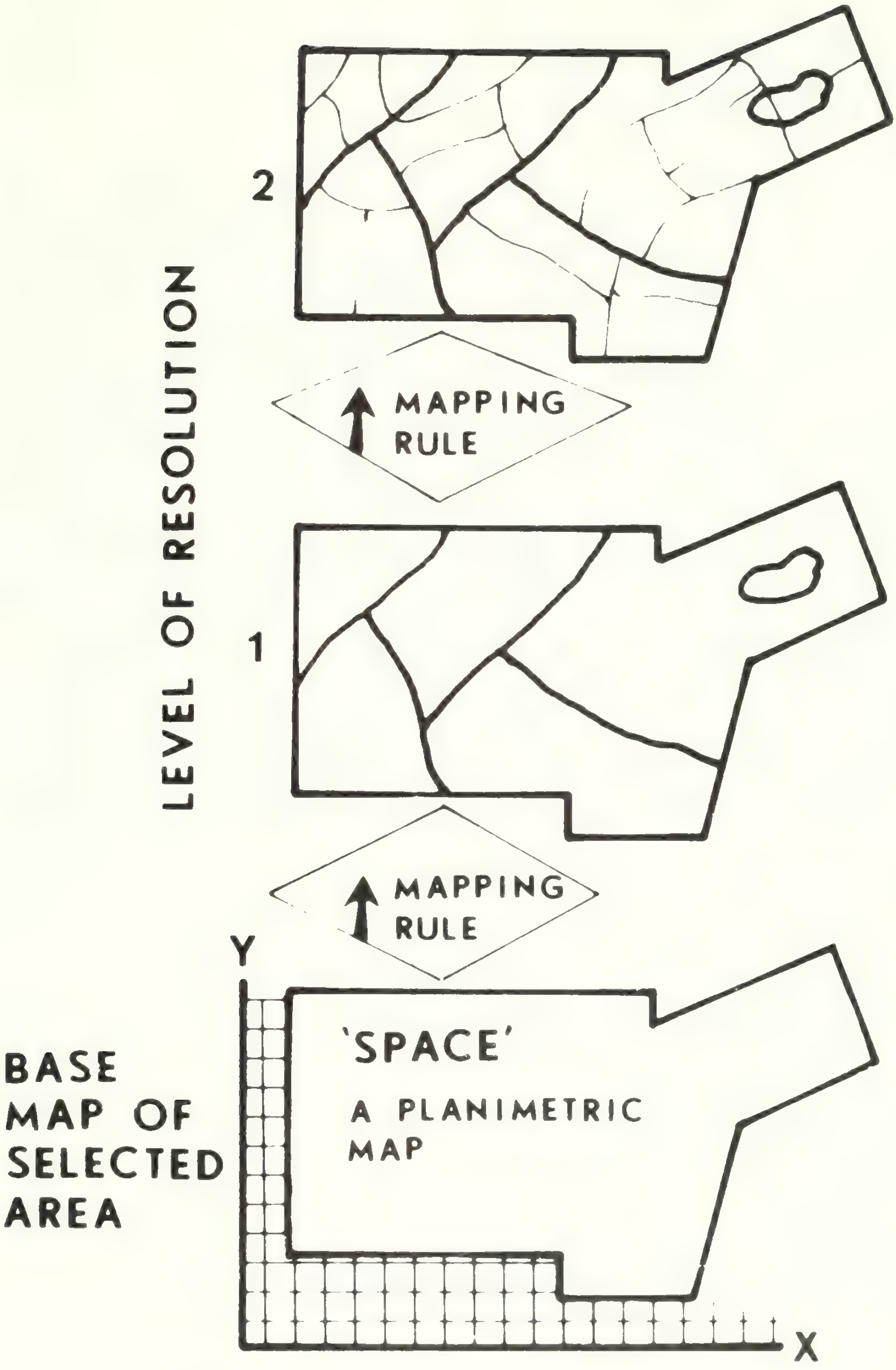


Figure 8. Regionalization: Classifying and delineation of space on the basis of environmental affinities and relationships.

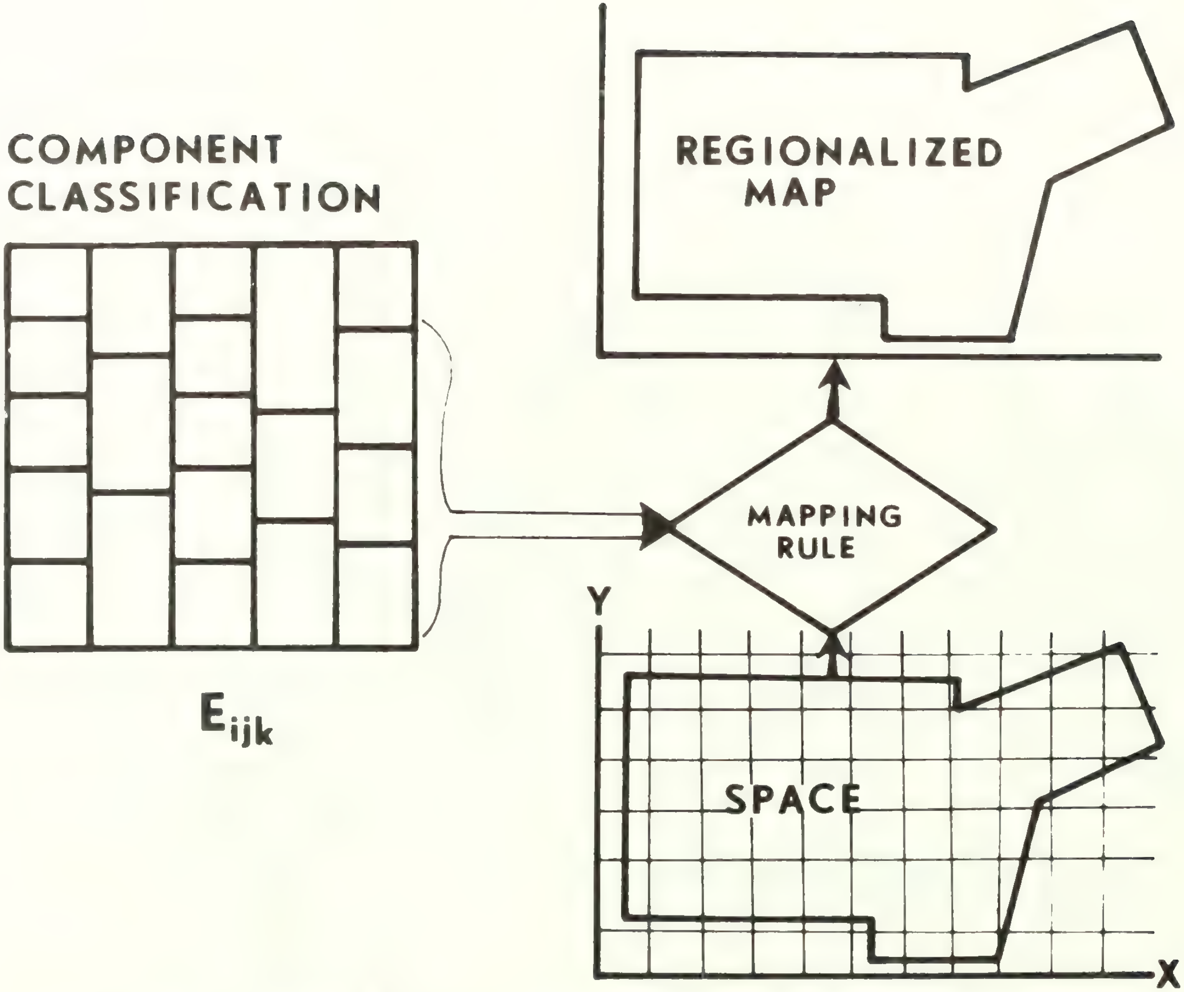


Figure 9. Relationship of component classification to regionalization through mapping rules--the environmental affinities are identified and delineated using mapping rules operating on the measurable environmental attributes.

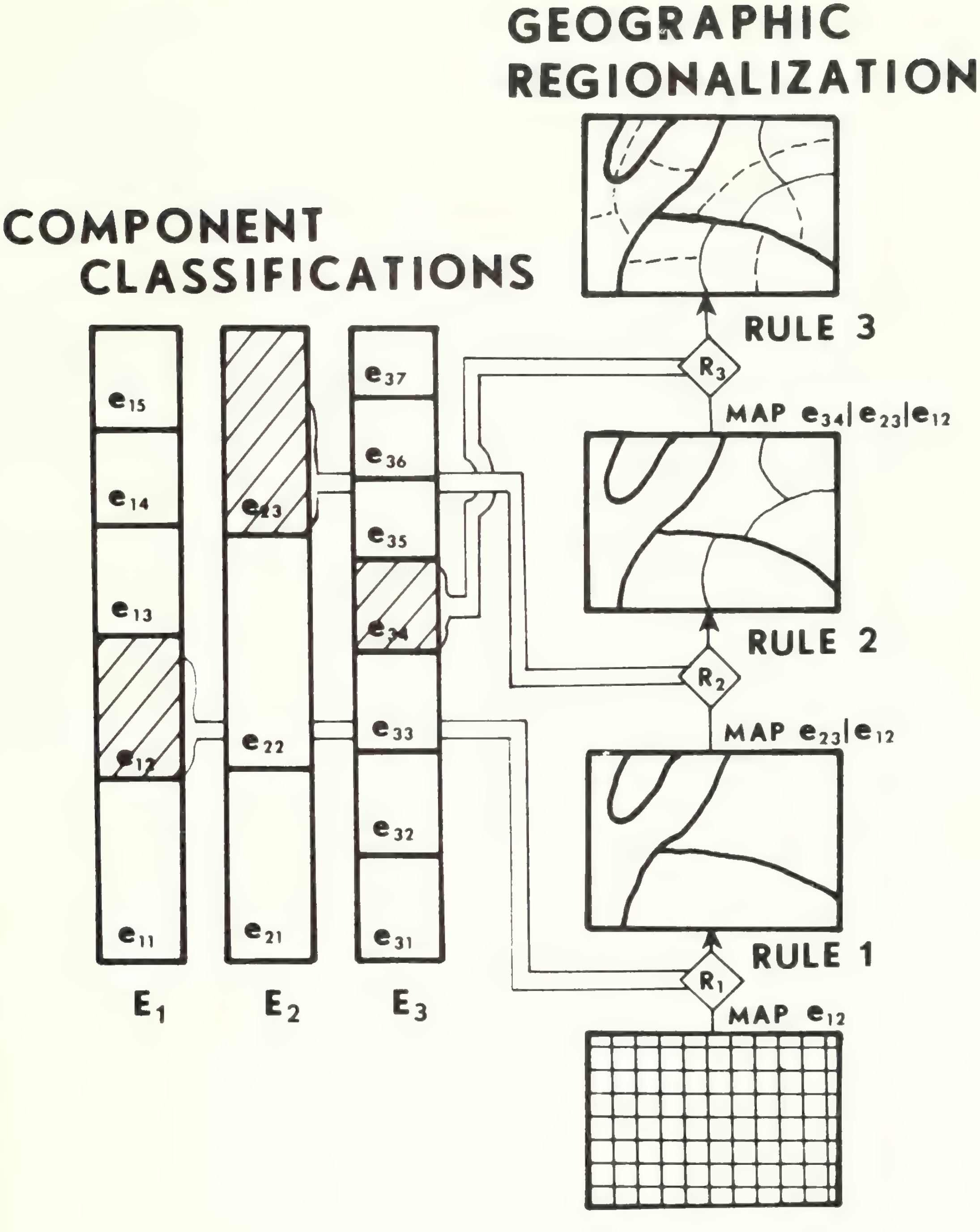


Figure 10. Mapping rules--an example.

Integration also tends to work with components at close to the same hierarchical level of detail whereas in regionalization the resolution of the components differs and tends to match the levels of the hierarchy.

An important consideration to remember in using regionalization is that much of the information system will normally be stratified and accessed by the components of the environment. If the regions defined on the map are to use this information for management, then it is critical that the mapping rules be explicit and be followed.

Since we must have geographically "regionalized" maps to delineate land for planning, prescriptive, and program implementation purposes, then it seems doubly important to preserve the mapping rules. Otherwise we will have the research and information-gathering folks using the component approach and the managers and program implementation folks using regionalized maps which are not adequately defined for access to the information system. The mapping rule is the critical link and, in a way, can be thought of as the extension function between research and management.

The logic of mapping rules for regionalized classification and the "integrating" rules for integrated classification need attention. Why are we regionalizing or integrating? In all the examples we have seen, the purpose is to identify and/or map environments that are homogeneous in some respect: with regard to productivity (timber, range, or fish), with respect to environmental sensitivity (erosion, visual vulnerability, mass failure, pollution potential, etc.) or for some regulatory, administrative, planning, or legal purposes (subsidies, pollution regulation, budgeting, etc.). There are obviously many reasons to regionalize and delineate space. We simply need to spend more time and effort determining exactly what these reasons are and then testing mapping rules to find rules cost-effective for the purpose.

A CLASSIFICATION OF CLASSIFICATION SYSTEMS

As a brief conclusion to this paper several elements of the preceding discussions can be pulled together to outline a classification of classification systems. Hopefully this will help discussion and prevent us from falling into the mental trap of thinking that all systems are competitive and the issue is which brand is best!

For this task we have used two criteria[1/]: (1) Degree of information synthesis (using the symbolic language from the model of problem solving) and (2) place specificity.

[1/] A useful third criterion would be the orientation of the classifier into the "romantic" or "classical" dichotomy presented by Robert Pirsig in Zen and the Art of Motorcycle Maintenance. Romantics are more concerned with feelings and the operation of the whole whereas classicists are prone to measurement and disassembly of wholes into their component parts. While we are clearly taking a "classical" approach in this paper, we also recognize the "romantic" necessity of considering whole, integrated ecosystems...it is just that we want to document such consideration for the benefit of future planners.

I. Degree of Information Synthesis

(a) basic environmental characteristics (E_{ijk})

(b) biophysical integrations (X_I, X_{II})

(c) value interpretations (Q,P)

II. Place Specificity

(a) place-independent

(b) place specific

These two criteria provide us with a simple matrix (Figure 11). Mapping, integrating, and classifying rules are shown to connect the different cells of the matrix. To provoke discussion, we have tentatively located (without defense) some common classification systems within the tabular matrix. After this paper and these ideas receive proper criticism, and we have more time to document and research existing classification systems, then a more detailed analysis can be presented. The matrix illustrates that the place-independent components form a foundation for the more applied classifications and the rules are the vital linkage that relates sharing of information between systems.

CONCLUSION

Returning at last to the title objective of this paper, we can now recommend what we feel are desirable characteristics of a common conceptual and procedural framework for land and water classification.

1. Accept the idea that a family of related classification systems is needed, and that a single system cannot cover all needs.

2. The foundation of this family should be the set of relatively stable and separate component classifications (such as bedrock, soil, climate, potential vegetation, etc.).

3. Each of these separate components should be hierarchically classified using objective procedures with field identification based on observable, measurable attributes.

4. Classifications which are regionalizations or integrations of the components should be designed for a stated purpose. The mapping and integrating rules operate on the foundation set of component classifications and need to be made explicit for effective access to available information.

5. Experience, knowledge, and data about land and water gathered by research and management should be identified, labeled, and stored by the component classification.

6. Applied classifications should be conceptually and empirically validated against their stated purpose; that is, if some item of information is supposed to be predicted by a classification, then experiments should be performed to see if this is true.

7. The logic and language of all classification should be understandable and communicable to the nonspecialist.

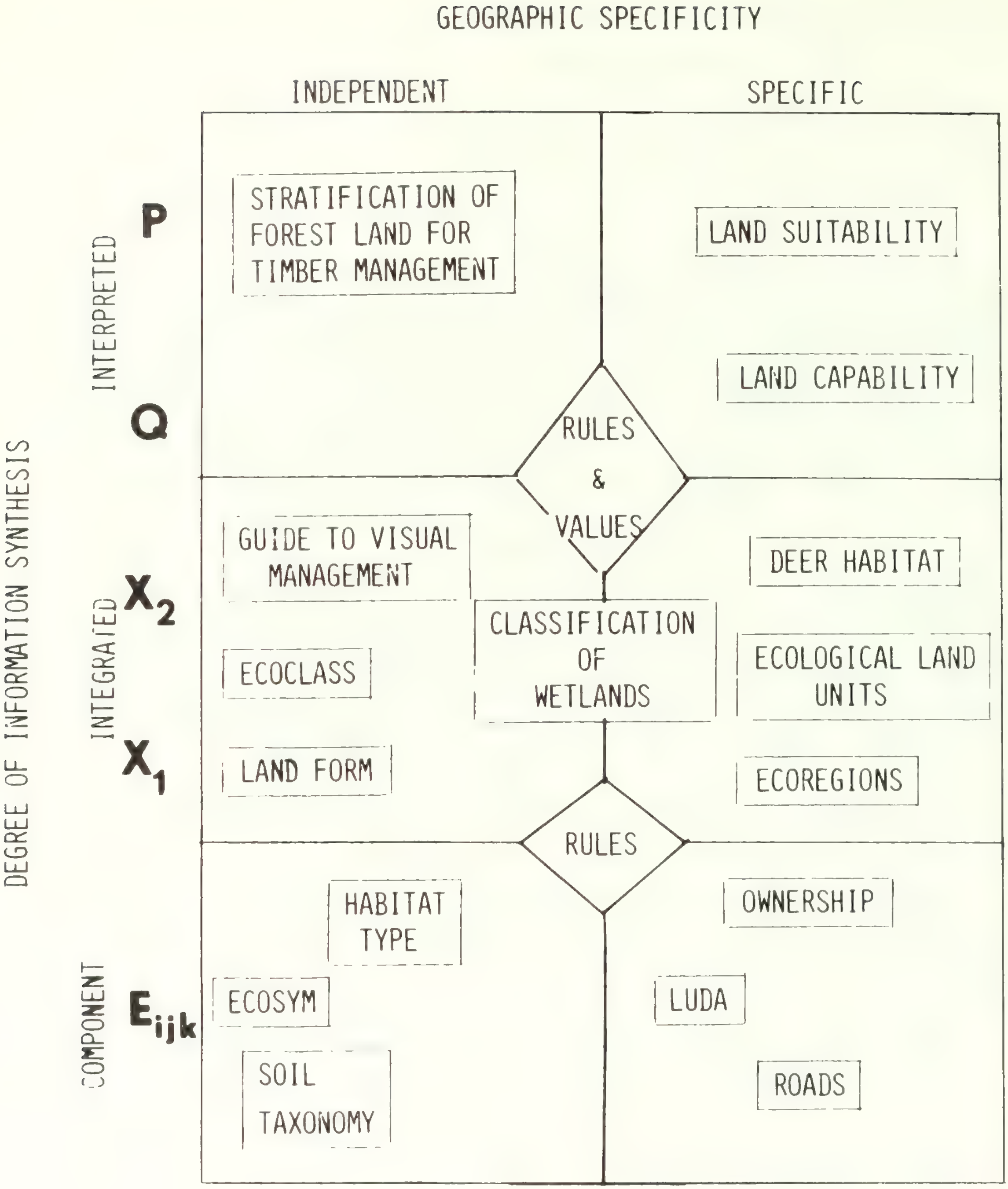


Figure 11. A tentative classification of some current classification systems.

NATIONAL ASSESSMENT NEEDS

Richard S. Driscoll
U.S.D.A., Forest Service
Rocky Mountain Forest and Range
Experiment Station
Fort Collins, Colorado 80521

Abstract: National assessment needs for wildlife and fish habitat are arrayed into five general groups: 1. A Determination of Information Needs: This includes area, extent, geographic location, and structure of vegetation type; kind of substrate within the types to evaluate soils and topography; ecological successional stages of the vegetation; and periodicity of food productivity. 2. Resource Classification: A compatible, among agencies, and ecological classification system is required to mesh data from different sources. 3. Resource Inventory: Compatible resource inventory systems are required so that data are collected similarly, withdrawn from compatible data bases for analyses, and are multifunctional to realistically evaluate and assess interactions. 4. Analytical Procedures: Improved analytical procedures need to be developed so that national assessments are based on habitat quality and quantity as well as output products. 5. Data Management Systems: Compatible information and data management systems are required to provide rapid access to date and information.

Public Law 93-378, the Forest and Rangeland Renewable Resources Planning Act, was enacted on 17 August 1974. This Act, in part, directs the Secretary of Agriculture to prepare a Renewable Resource Assessment; the first in 1975, an update in 1979, and a new assessment each decade thereafter. The Act further states that the Assessment shall include: "(1) an analysis of present and anticipated uses, demands for, and supply of the renewable resources...and (2) an inventory, based on information developed by the Forest Service and other Federal agencies, of present and potential renewable resources, and an evaluation of opportunities for improving their yield of tangible and intangible goods and services..." In carrying out the Act, "...the Secretary of Agriculture shall utilize information and data available from other Federal, State, and private organizations and shall avoid duplication and overlap of resource assessment and program planning efforts of other agencies."

The Assessment is to consider all the approximately 1.6 billion acres (647,360,000 ha.) of forest and rangeland of the United States, its territories and possessions. The Assessment does exclude lands in use for agriculture, urban areas, and transportation corridors. However, considering wildlife and fish habitat, these lands cannot be ignored because they do provide critical life support requirements for some species. For example, many migratory waterfowl depend on farm ponds and fields for resting and feeding and, in some cases, nesting, breeding and brood rearing.

With passage of the Resources Planning Act, and in coordination and cooperation with other renewable resource agencies, States, and the public, the Secretary of Agriculture, through the Forest Service, has the mandate to coordinate a comprehensive assessment of the state of the Nation's natural renewable resources. These data will provide information for decisionmakers to allocate land, water, labor, and capital resources in the most efficient way to meet society needs and demands within the ecological limits of the land and water base.

National or regional assessment needs for wildlife and fish habitat require information on what the resources are, where they are, and how much is there. All of the resource systems, wildlife and fish habitat, range, and timber, are functional and product oriented. However, there are primary resource elements--vegetation, soil, and water--common across all resource systems. After the what, where, and how much questions are answered, then analytical techniques that are functional and resource interaction oriented, will produce information to evaluate the state of the Nation's wildlife and fish habitat.

THE PROBLEM

Wildlife and fish habitat assessments are interpretative based on data and information about primary resources--vegetation, soil, and water. The interpretations must include interactive relationships with other resource systems. These assessments must be done in such a way that they provide consistent and compatible results at all levels of decisionmaking. The process must allow program recommendations for wildlife and fish habitat that are as efficient and effective as possible.

Wildlife and fish habitat assessments, as well as assessments for other resource systems, have traditionally been fragmented within and among natural resource agencies to meet particular objectives even though the objectives may be similar. Consequently, a comprehensive assessment of the state of the Nation's wildlife and fish habitat and other resource systems is difficult and imprecise. Many factors contribute to the dilemma, including the lack of:

1. A classification system amenable to hierarchical aggregation and disaggregation of resource values. There are many land and resource classification systems in use or available. With few exceptions there has been little effort to integrate the systems so that data and information can be consistently aggregated and disaggregated with geographic fidelity to allow efficient and effective integrated management.

2. Quick and efficient resource inventory procedures responsive to rapid updating to the current resource situation. Most resource inventory procedures are ground-based, time consuming, and are not amenable to seasonal requirements of wildlife and fish populations. For example, inventories to determine food quantities on many western big game ranges may be conducted in the summer when vegetation is at peak growth. Likewise, food inventories for fish may be completed during peak production periods. These data present distorted notions of the forage quantity and quality likely to occur during stress periods.

3. Adequate techniques for analyzing the data once it is available. Most analyses have been made while considering known and inferred requirements of single animal species. Also, most analyses have only slightly considered habitat and animal diversity in relation to the potential of an area to produce variable goods and services. Analytical techniques on cause-effect relationships of resource management strategies are lacking.

4. Readily accessible data storage and retrieval systems. Where in the nation can we push a button and bring up data and information about mule deer

habitat or rainbow trout habitat without first spending man-months of time searching file drawers, sometimes folder by folder, and summarizing the information?

A SOLUTION

Wildlife and fish habitat assessments, or assessments for other resource systems, require sequential and iterative process elements which include:

1. Determination of information needs and requirements for national, regional, or local assessments.

2. Establishment of a resource classification system that is hierarchical and efficient for national, regional, and local assessments to develop resource program alternatives and recommendations.

3. A resource inventory system that is responsive to the information needs and requirements and the resource classification scheme.

4. The development of analytical procedures for current and future resource supplies in relation to demands, accessibility, potential, economic variances, investments, and alternative institutional and other social constraints.

5. The development of effective mechanisms for storage, retrieval, update, and display of large data bases required for national, regional, and local evaluations.

INFORMATION NEEDS

It is doubtful that there will ever exist complete consensus on what parameters should be measured to assess the state of the Nation's wildlife and fish habitat. There is a wide spectrum of needs from top management to the field biologist or resource manager. However, there are certain parameters that are common assessment requirements throughout the decisionmaking hierarchy.

AREA, EXTENT, GEOGRAPHIC LOCATION, AND STRUCTURE OF VEGETATION TYPES

What these vegetation types are depends on the classification system used but they must be ecologically oriented to assure common response coefficients for specific management goals. Extent and location must consider juxtaposition with other vegetation types to give a measure of between-type diversity. Structure refers to a three-dimensional picture of the vegetational components, within a type, to provide a measure of diversity.

KIND OF SUBSTRATE WITHIN THE TYPE

This refers to the abiotic features of the type and would include kind of soil and topography.

ECOLOGICAL SUCCESSIONAL STAGE

The seral stage of the vegetative types or water system in relation to external disturbances such as grazing by livestock or logging as these events might cause reduction of food and cover for terrestrial animals or siltation of streams and lakes that would affect fisheries.

PERIODICITY OF PRODUCTIVITY

Information is needed on seasonal productivity of food since food is a limiting factor in any wildlife or fish population. Intensity of measurement for national assessments would include only class categories of foods such as graminoids, herbaceous, shrubs, and certain classes of fish foods. Local and regional needs may require estimates of individual species but these can be aggregated into classes within a hierarchical system.

The above needs refer to basic elements of wildlife or fish habitat. There are other secondary information requirements to make habitat assessments. These include: (1) Location and extent of existing commercial and residential developments and estimates of pressures from expansion of these developments; (2) land ownership including private lands and those administered by different agencies; (3) regional and local land use planning goals; (4) values for other resource systems to interpret interactive relationships affecting wildlife and fish habitat; and (5) location and extent of critical areas for those wildlife and fish species we have sufficient data about especially those listed as rare, threatened, or endangered.

The above is not an exhaustive list of all information needs for national assessments of wildlife and fish habitat. It does include essential elements. Others will need to be added as we learn more about how to make such national assessments.

RESOURCE CLASSIFICATION

We can ill-afford to continue to use only functional resource classification systems that may be nationally, regionally, or locally oriented. Near chaos has occurred when attempts have been made to mesh these classification systems for resource system assessments or to provide basic statistics of the nature of the Nation's land and water resources. For example, a timber type and range type map, prepared according to existing specifications, would match only by chance if the requirements were to determine area statistics of basic vegetation classes.

Classification is used for two basic purposes: (1) to provide stratification for sampling various resource parameters, and (2) to provide location data and information for efficient and effective application of resource management programs. Stratification improves cost/effectiveness of sampling strategies. Location specifics allow for opportunities to select areas most suitable for specific resource program alternatives.

There are two basic kinds of classifications: (1) Natural, or primary, which deal with fundamental data, and (2) technical, or secondary, which deal with characteristics specific to a particular resource system.

Natural classifications are made without predetermined considerations for use; they are classifications made in relation to ecological constraints in which the class categories will reflect similar reactions to specific kinds of management practices. The characters and character states are based on primary properties of the class, i.e., foliage over and production of graminoid, herbaceous, shrub, and tree species; slope, aspect and elevation; water salinity; hydrogen ion concentration; and mineral content.

Technical classifications are based on preconceived notions of product output. Examples of technical classifications include commercial and non-commercial timberlands, usable and non-usable livestock range, good and poor animal habitat in relation to human intervention, good and poor browse species for mule deer, and good and poor water bodies for rainbow trout. Technical classifications permit specific questions to be answered in relation to specific functional uses and management.

However, using only technical classifications will result in such events as double-counting of land area and duplication of work on specific land areas. Technical classifications can be derived from natural systems depending on local, regional, and national needs. Since natural classifications are based on the natural properties of vegetation, soil, and water, and data about these properties are required for assessments of any resource system, a natural classification system must be devised to meet national assessment needs. Within this system, classification specific to wildlife and fish habitat can be developed.

RESOURCE INVENTORY

As previously mentioned, most resource inventory techniques are ground based, time consuming, and frequently lead to misconceptions about the true nature of the resource situation. Also, most resource inventory procedures are void of periodic and continuous updating.

A basic constraint of future resource inventory systems is that resource assessments and evaluation, regardless of the resource management system, can be made from a common data base. This does not mean that past inventory procedures will be stopped and the data and information derived from them will be archived. It does mean that future inventories must be made with multi-assessment and multievaluation objectives in mind.

For example, much of the data and information derived from livestock range, timber, and soil inventories are required to make assessments and evaluations for wildlife and fish habitat. It is recognized that all resource parameters specific to a particular resource management system may not be included in a multiresource inventory system. However, major elements of the inventory would be included in a multisystem and subinventory system for data very specific to wildlife and fish habitat assessments could be conducted simultaneously, or independently using a common base, as required.

Efficient sampling designs coupled with remote sensing capabilities need to be used to meet future demands for periodic and continuous factual data and information about wildlife and fish habitat. No agency or institution has the manpower and monetary resources to continue to conduct inventories in the traditional way. There are techniques emerging on use of improved remote sensing and sampling techniques that will improve the efficiency and accuracy of wildlife and fish habitat inventories. Integration and improvement of these techniques will increase the capabilities to make decadal national assessments of wildlife and fish habitat.

ANALYTICAL PROCEDURES

In many instances assessments of wildlife and fish habitat have been made on the basis of animals harvested, activity days involved, dollars spent to harvest products from the habitats, or time spent viewing animals. These are habitat outputs and, in the true sense of assessments, do give an indication of habitat value and trends of output supplies. They are subject to human whims of hunting, fishing, and viewing and provide only a facade of the true resource condition from which the products are derived or how the product outputs may be altered.

Idealistically, national habitat assessments would include evaluation of requirements and values for all animal species. This is not feasible because we have so little factual data about the requirements of the majority of the species occurring in the Nation, because of adaptation of species to different habitats, and because of the mobility and diversity of wildlife and fish populations. Techniques have been developed in Europe and, to an extent, in the United States whereby habitat assessments and evaluations are made in relation to groups of animal species with similar habitat requirements.

To meet national wildlife and fish habitat assessment needs, analytical techniques which take into account cause/effect relationships, within and among resource management alternatives, must be carried out. For example, if a wildlife management strategy is designed to increase seed-producing herbaceous plants in a forest ecosystem to entice birds for esthetic viewing, we must know what effect this strategy will have on timber-producing potential of that area. Likewise, we must know what effect livestock grazing in the Northern Great Plains pothole country has on waterfowl production.

Fundamentally, habitat assessment should begin with the local environment where habitat quality, quantity, and diversity determines the abundance or scarcity of any species or group of species. Through aggregation to regional and finally national assessments, we will be provided with a much better evaluation of the state of the Nation's wildlife and fish habitat.

DATA MANAGEMENT SYSTEMS

To make national habitat assessments, we need an information management system that avoids file-drawer searching to retrieve and/or update inventory data and information. The data files should be structured so that geographic locations are available and multiresource information is displayed. It is conceivable that such a system would be structured by a number of subsystems, each of which contains information relevant to a specific resource management system. The system should also be structured so that questions relevant to management alternatives can be answered.

There are many data management systems available. Some of them will be discussed later in the Symposium. Other like ECOSYM, under development by Utah State University, are undergoing validation. This work needs to continue with focus on operational capability within the next 3 to 5 years.

It is doubtful that there will be developed in the near future a common data base stored at one location on one computer system. We must strive for compatibility of data management systems among all units responsible for not only wildlife and fish habitat assessments, but assessments of other resource systems.

CLASSIFICATION AND INVENTORY FOR THE PERPETUATION OF ECOLOGICAL DIVERSITY

Dr. Robert E. Jenkins
Vice President, Science Programs
The Nature Conservancy
1800 North Kent Street
Arlington, Virginia 22209

Abstract: Efforts to systematically preserve examples of all of the elements of ecological diversity extant in North America are described. The importance of rigorous, systematic effort is stressed and the State Natural Heritage programs, already operating in nearly a dozen states, are described. The program employs a classification of the "elements of ecological diversity" consisting mainly of biological community/ecosystems types and special species habitats. A cyclical inventory process is employed to collect information for a continuously operating, "balanced" information management system. These processes are used to create a dynamic atlas and data base on the existence, characteristics, numbers, conditions, status, location, and distribution of examples of the elements of natural ecological diversity. The ultimate purpose is to select and protect adequate representatives of each of the elements so as to perpetuate the fullest possible array of species, communities, and other ecological components and phenomena.

INTRODUCTION

It is a little difficult for me to talk about perpetuating ecological diversity through natural area programs from strictly a user's perspective. This is because over the years The Nature Conservancy has been a major force in collecting, classifying, organizing, and analyzing ecological data as well as in applying it through protection programs. We have developed research and data operations reciprocally with acquisition and protection so that the approach I describe has developed as a link between theory and action.

It may first be useful to provide a brief statement about ecological diversity. The objectives of the "natural areas movement" have often been obscured by the ambiguity of the term natural area, but the true purpose of The Nature Conservancy, for instance, has always been to act as the Noah of the conservation movement by attempting to protect adequate examples of the full array of species, ecological communities, and other natural features and phenomena from extinction or endangerment in the face of pervasive and destructive development. The only other basic issue in ecological conservation, it seems to me, is the maintenance of ecosystem function (or the health of the life support systems). Of course, much of the ecological conservation activity in this country falls between these two poles, being preoccupied with the relative abundance among species, communities, and other ecological types and phenomena to achieve some desired end.

All of these considerations are significant, but it is important to distinguish among them because lumping them together tends to obscure important issues and hinder effective decision making. We have chosen to concentrate on diversity for several reasons. First, we believe it is valuable to specialize, because far too much energy is being dissipated by institutions attempting to solve every problem simultaneously. Second, we believe it is important to maintain ecological diversity for a number of reasons, which should be well understood by this audience (Humke et. al., 1975, Ehrenfeld 1976, Oldfield 1976). Third, because the extinction of species or communities is irreversible, and the degree of their endangerment grows steadily worse. And lastly, we believe that the perpetuation of ecological diversity can be feasibly accomplished under prevailing demographic, social, economic, and legal conditions.

We define ecological diversity as the sum total of: (1) diversity of genetic information, best exemplified by the gene pools represented by biological species; (2) variety of biological communities into which these species are organized; (3) physical and biological attributes of types of ecosystems and of the ecosystems themselves; and (4) whatever other irreplaceable types of ecological entities and phenomena may be identified. These ecological entities, which we characterize as the "elements of ecological diversity," all exist as systems or parts of systems, and must be perpetuated as such. Therefore, the most cost-effective, and possibly the only, way to perpetuate diversity is in situ, as a collection of nature preserves on which adequate examples of the full range of elements are protected. Competition for the use of remaining natural lands is intensifying, and since there are only limited resources with which to counter the destructive and homogenizing effects of this increasing pressure, it is crucial to identify those parts of the total landscape which must be protected in order to provide "lifeboats" for the fullest possible array of ecological elements.

From a user's perspective then, who can tell us which lands are critical or provide the information necessary to make such judgments? It turns out that such information has not been available. Environmental survey efforts have either not quite focused on the objective or have been incapable of properly collecting and organizing the information. This vacuum has existed for a long time, and there have been many attempts, largely privately financed and conducted, to fill the gap through so-called natural areas inventories. Probably the first of these was begun in 1917 by the Ecological Society of America's Committee for the Preservation for Natural Conditions (the precursor body to The Nature Conservancy). Such efforts have proliferated in the intervening years (Jenkins, 1973, Romancier, 1974, Laycock, 1975). For reasons too numerous to mention here (Jenkins, 1975, 1976), these efforts have largely fallen short of their goal, but they have taught us many important lessons. Over the last several years, the Conservancy, in cooperation with a number of State and Federal agencies, has been distilling these lessons into a more effective approach. This discussion will focus primarily on the concepts and methodologies employed in classification and inventory. Later in this Proceedings, Moyseenko discusses the information management system (Moyseenko et. al., 1976; Jenkins et. al, 1976).

HERITAGE INVENTORIES

The approach described here has mainly been developed under the auspices of the Conservancy's State-oriented Natural Heritage Programs, although certain aspects have been refined through a variety of national inventory efforts. Natural Heritage Programs are conducted in cooperation with State governments or other agencies, usually under a 1- to 2-year contract. During this period, a systematic process for the collection, management, analysis, and use of relevant ecological data is established, in conjunction with multidimensional protection plans, and thereafter transferred to the governmental agency for continuation and implementation. There are now nearly 12 individual programs covering about 20 percent of the conterminous United States. At the national level, we are drawing together information from the various Heritage Programs and combining it with information in a National Science Foundation financed, computer-mediated, national data bank on scientific research reserves, with data on Nature Conservancy reserves, and with certain broad-scale inventories.

CLASSIFICATION

As Frank Egler says, "Ecosystems are not only more complex than we think, they are more complex than we can think." In order to deal with this literally incomprehensible complexity, for whatever purpose, none of us have any choice but to take a strenuously reductionist approach. Ecosystem structure and function analysts may employ simulation modeling; diversity analysts are driven to classification.

Reductionism means making hard choices about which aspects to emphasize and which to disregard. No single set of choices can ever satisfy everyone or every purpose, so there will never be a single universal classification system. One of the biggest hurdles we have had to get over in our programs was to stop trying to create one and to recognize that it is both necessary and legitimate to tailor our efforts to our own purposes. We could not simultaneously excel in geology, soils science, ecosystem analysis, hydrological engineering, transportation planning, ad infinitum, and it was only confusing us to try to look at landscapes through all those eyes. We have restricted ourselves instead to classifying ecological diversity. The primary strengths of this approach are its basic simplicity and the clarity of an uncluttered disciplinary focus. All of our subsequent experience has reinforced the wisdom of this course of action, and it is clear that such a limitation of intent has actually increased the scope of applicability of our output.

Essentially, we have quit trying to classify or analyze landscape per se but have set out instead to create an efficient classification of the "elements of ecological diversity." Among possible entities which might be so designated, species are by far the most satisfactorily classified. The existing classification system has evolved over 200 years and is in current use throughout the world. Therefore, the first class of "elements" in our system consists of species themselves. Of course, this poses some problems in that there are so many species, and many are very little known. Fortunately, a great many of them are not yet in any particular need of protection, so as a practical matter we concentrate on those known to be rare, endangered, threatened, endemic, etc., which we collectively denote as "special species." To determine which qualify, we ordinarily use a combination of State and Federal lists, available literature, and the opinions of local experts; to which we add whichever other species are persuasively recommended. In the process we include a certain number of subspecies or other infra-specific taxa as we think appropriate.

For the many other species, both those which are common and those in little known groups such as insects, we have little choice but to employ coarser methods. For this, we operate on the accurate and simplifying assumption that all species exist as parts of biological communities. Recognizable community types are another target of our inquiries, consequently the Conservancy hopes to "capture" adequate populations of most of the rest of the species by dealing with communities themselves. Plant communities constitute a more abstract class of "elements" in our classification system and serve besides as a sort of coarse filter for species.

Terrestrial plant communities have received much attention and are perhaps the second most satisfactorily classified entities, though they are a very distant second. We employ essentially the same strategy here as with "special species" in that we use existing classification systems wherever we can. In many states, there are highly defined plant community classifications in wide use among vegetation scientists; in other states, we have had to develop a classification. Though the form of the classification is typological, the individual plant community types or elements are actually related to a hierarchal taxonomy which facilitates the recognition and placement of intermediate types and where necessary, the redefinition of types.

It is admittedly even more difficult to deal with aquatic communities. Perhaps because the biological properties of aquatic systems are less evident and more dynamic than those of terrestrial ones, no one seems to have tailored classifications systems to our needs. Since we have concluded the necessity of incorporating some typological parallel to terrestrial communities, we have done the best we could by attacking the problem in various ways. In some states, we have adopted the Fish and Wildlife Service's new wetland classification system, with or without modifications; in some we have developed a permutation of hydrological types and drainage basins; and in others we have adopted some appropriate scheme developed by regional scientists.

One further point should perhaps be made about the relationship between species and communities (or habitats). It is obvious, but often overlooked, that not all species are equally adaptable, which is a major reason why some are extremely abundant and others are quite rare. For this reason, the approach used to define habitat for common species like whitetail deer using cover type, seral stages, productivity, etc. is not particularly applicable to most rare and endangered species. In other words, for very adaptable species it is possible to predict their presence, or even their abundance, with some accuracy from secondary indicators such as vegetation type. But narrowly adapted rare species are much more sensitive to limitations in their environment than our gross methods or instruments. In other words, bog is much too generic in term to describe bog turtle habitat, because they may only be found in 1 bog out of 100. To protect a bog turtle, do not try to define a critical habitat type, but find a place with bog turtles! This is a necessary precept if we are to avoid mistakes and the waste of resources in either inventory or attempts at protection.

Each of these element classes constitutes a dynamic list. We can add or delete individual elements as increasing knowledge may dictate. In the cases of plant communities and aquatic habitats, elements may be aggregated or subdivided, or the entire system may even be reformulated. New elements or whole new classes of elements which are neither species nor communities may also be recognized. In most state systems, we maintain a miscellaneous class incorporating such elements as breeding concentrations and outstanding specimens. In several instances, the system has been extended beyond the purely biological as individual State cooperators have seen fit to incorporate classes such as geological, historical, archaeological, or even recreational element types. The many parallels between these sorts of diversity and ecological diversity can readily be seen.

Of course, occurrences of the elements defined by our classification (and other forms of classification) are not found in isolation on the landscape. There are large overlaps even among the various elements and classes of elements to be found within our system. For example, a single piece of woodland may hold all or parts of the home ranges of several different endangered species. Such overlaps are not problems, but the impulse to universalize the classification system by eliminating overlaps may create a very serious problem. One piece of landscape may be classifiable as a shrub bog because of its vegetation, a peatland on the basis of its soil, an intermittent pond on the basis of its hydrology, and a lesser whorled pogonia habitat from an endangered species perspective. Some classification concepts would lead to designating the area as an "intermittently ponding-peaty-shrub bog-lesser whorled pegonia habitat"--but that way lies madness. Such an approach leads quickly to a sort of circularity in which the reductionist power of classification is destroyed, and every single piece of the landscape turns out to be as unique as a fingerprint. Complex reaggregation of various collocated landscape elements may be crucial at the stage of analysis, but it is fatal in the fundamental classification.

The form of the typical Heritage classification can be represented (Figure 1). For our purposes, the total system functions as a sort of combined coarse and fine filter to efficiently "capture" the fullest possible diversity of ecological entities and phenomena.

STRUCTURE OF THE INFORMATION SYSTEM

To restate our objective in developing such a classification system, it is to create a set of defined objectives for our inventory and protection efforts. Individual elements serve as both targets for information gathering and as indices for information organization. Our proximal purpose is to organize a dynamic atlas of information on the existence, characteristics, numbers, condition, status, location, and distribution of examples (or "occurrences") of these elements.

To accomplish this we have developed a rather sophisticated, "balanced information management system" and trained new employees and cooperators in its use in inventory and analysis. Moyseenko discusses the system in detail in this Proceedings, but it is useful to provide a brief sketch here.

The information system is designed to store, retrieve, and combine various kinds of information derived from varied sources through a multimedia system of interlocking manual, map, and computer files. For efficiency and cost-effectiveness, we have relegated the great preponderance of data to nonautomated methods and file structures. No part of the total system needs to be thought of as computerized, although we have selectively identified and computerized key data categories for which automated storage and retrieval is especially convenient and useful. In fact, a great deal more of our systems used to be automated, and we have spent several years eliminating counterproductive data fields and spurious applications.

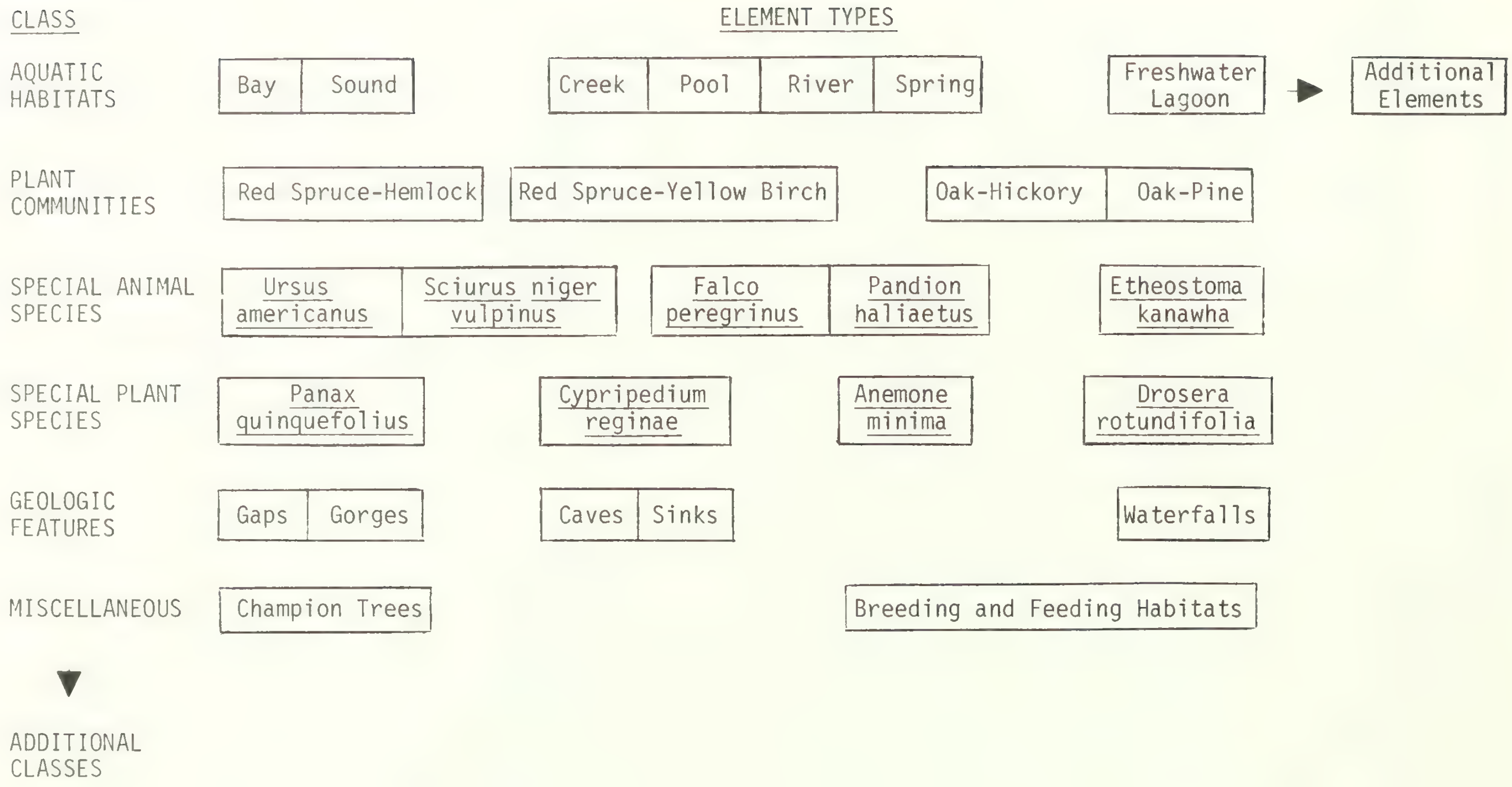


Figure 1. Classification of the elements of diversity.

One way of looking at the system is in terms of repetitive hierarchies like the outline of a theme. Table 1 attempts to represent the system from this perspective in which a basic data paradigm is applied to a series of "units of record" in essentially the same way. All of the parts and files are interrelated by compact codes which permit exceptional flexibility in system entry and use when intent and criteria vary. The whole system is documented and described in a rather voluminous manual of standard operating procedures to promote standardization and to facilitate independent use.

INVENTORY METHODS

Actual inventory proceeds from the assumption that field search for examples (or "occurrences") of the various elements is exceedingly inefficient. Many earlier natural area inventories aggravated this difficulty by restricting field investigations to sites delineated through nomination procedures which had little or nothing to do with ecological elements themselves, but were dictated by other factors such as lack of disturbances or scenic qualities. Therefore, the Conservancy concentrates inventory efforts to an unusual degree on secondary sources--earlier surveys, floras and monographs, museum collections, agency records, academic institutions, and the files and minds of individuals who have stumbled across many discoveries in the course of field work. Information derived from these disparate sources is digested and organized into the information systems in a way that I hope is self-explanatory. The emphasis throughout is on individual occurrences of each element in the classification.

The total integrated system works in two basic and related ways. The first is in continuing inventory or data gathering; the second is in supplying users with the products of the current information base. In the inventory process, we use the system primarily to highlight information gaps so that we can concentrate our limited resources attacking the most glaring areas of ignorance. This may involve searching for new secondary sources to supply leads to occurrences of elements not yet represented in the data base, various sorts of extensive and intensive field survey on known occurrences, or even the necessity of embarking upon de novo field searches where secondary sources have failed us. The data collection process operates as a cycle, accessing the same sources again and again to acquire increasingly refined information while adding more and less concentrated sources with every circuit.

An important concept is that we do not need (or want) to know everything about the landscape. Just as Noah did not try to save every elephant, our intent is not to manage every acre or element. Limited resources must be used efficiently to accomplish even the simple objective of preserving examples of each element, so the system constantly focuses attention on the most critical needs so that our capacities are fully employed in useful work.

When responding to users, the emphasis is not on gaps but on information already in the system and what it indicates. We have been careful to stick to "real" data wherever possible and to give little weight, space, or time to subjective scaling factors, coded opinions, or quantitative evaluation systems which only serve to mask and distort actual information. Structuring the data file into interlocking compartmentalized units is also of considerable importance because it enables us to aggregate or rearrange various information categories to respond to a wide variety of ad hoc queries and

Table 1: Conceptual Structure of the Information System.

Unit of Record	File[a]	Content	Current Medium	Comments
Element (as defined by classification)	General Element	Unformatted general information on the specific element--articles, citations, books, etc.	Manual	
	Element Abstract	Standard specific categories of information including description, nomenclature, range, special data management conventions, etc.	Manual[b]	
	Range Map	Separate map for each element	Manual	Maps and data attached to abstract
Element Occurrence (geographically disjunct examples)	General Element Occurrence	General information on each occurrence, field surveys, pre-existing records, etc.	Manual	Individual files aggregated by topographic quadrangle
	Element Occurrence Abstract	Standard specific categories of information including location coordinates, ownership, status, etc.	Computer	Various retrieval/query capabilities including mechanical map plotting
	Base Map	Location and ecological boundaries	Manual	Single map set covering region of survey
Managed Area (areas under conservation ownership or protection)	General Managed Area	General information including protection data, management, plans, ecological surveys, etc.	Manual	Individual files aggregated by managing agency--some selected information is computerized in auxiliary
	Managed Area	Standard specific categories of information including location	Computer	Various retrieval/query capabilities including mechanical map plotting

Table 1. Concluded

Unit of Record	File[a]	Content	Current Medium	Comments
Managed Area (continued)	Base Map	Location and legal boundaries	Manual	Same map series as for Element Occurrences
	General Information Source	Undifferentiated, unassimilated information of many types	Manual	
	Information Source Abstract	Standard specific categories of information	Manual[b]	
				No compelling uses have yet been found for map files on Information Sources
Other Units				

---

[a] Names used here do not always correspond to those used currently in operating programs.

[b] Computerization and other mechanical alternatives are being tested.

and disparate criteria. Even where data gaps exist, it is frequently possible to suggest probabilities or to specify what to look for. The system and the data bases have developed a wide usership because of the clarity and objectivity of the information products.

Among the uses to which the programs are being put, they are generating lists of critical areas as priorities for conservation acquisition, providing yardsticks for the evaluation of new opportunities, identifying important element occurrences on existing public lands, assisting various agencies to comply with current environmental laws, and acting as a crucial data resource for the proper review of environmental impact analyses. In each case, they bring a new dimension to the problem by providing broadly comparable objective information which can be used to illuminate relative values in an understandable manner.

I would like to take a few moments to relate our experiences to the wider themes of the Symposium. One important point relates to the appropriate geographic scale for classification and inventory efforts in this area of interest, and I suspect in others. The Conservancy has been involved in the full range of inventory possibilities from worldwide to national to regional to State to very local and has concluded that the State is the right focus for such efforts. Much larger regions exceed our capacities for accurate or consistent classification and impose nearly insuperable obstacles to data collection. Smaller areas provide insufficient scope for comparison. The State focus is also convenient because it permits close interaction with many government agencies, private organizations, and individuals, the activities and interests of which are circumscribed by State boundaries. Achieving a national perspective may best be accomplished by an additive process building on the efforts at the State level. To bring about such a coalescence will require standardization of methods and terminology.

Another important question concerns attention to basics. Unless we can build a strong real data foundation of a rigorous disciplinary nature, no successful interdisciplinary interactions can occur. A good bit of the difficulty experienced by planners and others attempting multifactorial landscape analysis is the weakness of the component data--just as the precision of computations is limited by the least precise factors in the equation. This is compounded, of course, by the inappropriate application of classification methods to description, description methods to classification, classification methods to analysis, and so on. Premature and ill-conceived attempts at interdisciplinary analysis are frequently only adisciplinary, and in the experience of the Conservancy, we have been able to derive little or nothing of any utility from them. On the other hand, our staff would give their eyeteeth for a clear, disciplinary classification of aquatic biological communities.

It is the belief of the Conservancy that more resources need to be put into the basic disciplinary labors of classification, inventory, and dynamic atlas creation especially for ecological information (perhaps the most currently deficient), but also for physical information on geology, geomorphology, soils, hydrology, and other basic landscape components.

There is a concomitant need for communication among workers in the different basic areas alluded to above, but such exchanges can also be a snare for the unwary. The Conservancy has as often been urged to create the "universal information system" as to create the universal classification system. Both requests are probably equally unrealistic. Our staff gradually cured themselves of pursuing the unattainable and set about looking for some minimum and sufficient basis for interaction. The solution arrived at is to rely on maps. The one true universal medium for cross disciplinary exchanges is the reasonably conservative surface of the earth. A single definable spot on that surface may be classifiable 100 different ways and subject to an infinite variation in description, but it is still the same spot on the earth. If the strength of this geographical benchmark can be extended through development of standards in terminology, georeferencing systems, map projections, plotting conventions, etc., so much the better. I have some hope that new remote sensing technology may help by displaying surface features, linearities, discontinuities, and the like which everyone is forced to recognize and acknowledge.

Coming back to our particular problem of perpetuating diversity, the Nature Conservancy could use some help, especially with various sorts of field survey. Not only do we need cooperating manpower resources to conduct extensive and intensive surveys, but in some instances we are not even satisfied with our methodologies and could use help and advice in that area. Ultimately we must go even a step further and design the preserves to be established. This includes system considerations of ecological viability, defensibility, and manageability, bridging the gaps to functional analysis of ecosystems, wildlife management, population genetics, etc. At that point I can assume a "user perspective" with few reservations.

LITERATURE CITED

Ehrenfeld, D.W. 1972. Conserving Life on Earth. Oxford Univ. Press, New York. 360 pp.

Humke, J.W., B.S. Tindall, R.E. Jenkins, H.L. Wieting, Jr., and M.S. Lukowski. The Preservation of Natural Diversity: A Survey and Recommendations. The Nat. Conservancy, Arlington, Virginia. 212 pp.

Jenkins, R.E. 1973. The preservation of ecosystems: A status report. Atlantic Naturalist 28(2):44-50.

Jenkins, R.E. 1975. Heritage programs: Inventory progress report. The Nature Conservancy News 25(2):26-27.

Jenkins, R.E. 1976. Maintenance of Natural Diversity: Approaches and Recommendations. Trans. Wild. and Nat. Resourc. Conf. 41:441-451.

Jenkins, R.E., H.P. Moyseenko, J.B. Merikangas, M.P. Coffield, C.A. Creed, S.S. Hartstack, F. Lepple, E. Rejuney, K. Wright, C.J. Orwant, J.L. Woodall, and S.A. Wood. 1976. Creation of a Data Bank on Established Scientific Ecological Reserves. Final Report. (Contract BMS-75-20321). 299 pp.

Laycock, W.A. 1975. Rangeland Reference Areas. Soc. Range Manage. Denver, Colorado.

Moyseenko, H.P., D.F. Furney, R.E. Jenkins, and L.A. Miller. 1976. Lowest Common Denominator Element File: An Information Management System. The Nat. Conservancy, Arlington, Virginia. 50 pp.

Oldfield, M.L. 1976. The Utilization and Conservation of Genetic Resources: An Economic Analysis. Master of Sci. Thesis, The Pennsylvania State University. 232 pp.

Romancier, R.M. 1974. Natural area programs. J. Forestry 71(1):37-42.

HABITAT CLASSIFICATION AND THE REGULATION OF CRITICAL AREAS

Dr. Jon A. Kusler
Attorney at Law
Environmental Law Institute
Washington, D.C.

STATE AND LOCAL CRITERIA AREA REGULATORY EFFORTS

A close look at state and local land use control efforts in the last decade reveals a startling shift from traditional status quo zoning based upon existing land uses to emphasis upon natural resources. This refocusing reflects increased sensitivity to environmental values, Federal incentives, and a realization that fixed natural resources must meet not only present but future needs.

Since 1964, states have adopted at least 90 critical area regulatory programs. A monograph discusses these programs in depth (Kusler, Regulating Sensitive Lands: A Challenge in Resource Allocation, Environmental Law Institute, Washington, D.C.). The programs form the main thrust of the so-called "quiet revolution" to State land use control and include floodplain and floodway programs in 24 states, coastal zone programs of one sort or another in 16 states, wetland programs in 15 states, inland lake and stream shore programs in 6 states, and scenic and wild river programs in approximately 25 states.

Despite all of the fuss about a quiet revolution, most programs are cooperative state/local efforts with state definition of areas and standard-setting, and local administration and enforcement. This is important. State land classification and data gathering needs are, to a considerable extent, determined by local needs. More than 14,000 local units of government have adopted or indicated an intent to adopt floodplain regulations as part of the National Flood Insurance Program or in response to state regulatory efforts. More than 1,000 communities have adopted lake and stream shore zoning and another 1,000 have adopted wetland controls. An undetermined number have adopted special coastal area, forestry, scenic and wild river, conservancy, or other controls.

State and local critical programs are, in effect, efforts to classify and inventory lands based upon natural resource capability for the purpose of applying particular land development policies. This goal is related, of course, to the topic of the present symposium. Classification is typically linked to one of two development policies: either (1) complete prohibition of development within areas, or more commonly, (2) application of performance standards for permitted uses. State agencies typically map critical areas in cooperation with Federal agencies and local units of government. Local units evaluate individual proposed uses on a case-by-case basis to determine their consistency with performance guidelines.

SIGNIFICANCE OF PROGRAMS TO A NATIONAL HABITAT CLASSIFICATION AND INVENTORY EFFORT

More specifically, how are these programs relevant to the present symposium? First, State and local critical area regulatory programs are major potential clients for a national habitat classification and inventory effort. Lack of habitat data has been a serious deficiency in coastal zone, shoreland, and scenic and wild river programs. Very little habitat information has been available to define subzones or evaluate individual proposed uses.

Second, State and local critical area programs offer important lessons for a national habitat classification and inventory effort. An overview of these programs reveals considerable similarity in the basic principles and needs of land classification for regulatory purposes despite differences from state to state in the types of areas addressed, topography, vegetation, and political climate. These principles and needs, in general, also apply to land acquisition, environmental impact analysis, and other site-specific implementation.

I suggest six principles.

PRINCIPLES FOR A NATIONAL CLASSIFICATION SYSTEM AND INVENTORY

First, attempts to classify habitat should be management-oriented. Attempts to select relevant characteristics or groups of characteristics from the myriad of natural resource and cultural parameters available should have a management focus. Relevancy for scientific purposes may be different from relevancy for management purposes. For example, a scientific classification based upon differences in vegetation and wildlife would usually not consider uniqueness, sensitivity to damage, and threats from development which are important to management.

Second, classification schemes should be capable of translation into simple and understandable terms. A sophisticated scientific taxonomy to describe habitat is desirable for certain purposes and might serve all purposes if scientists managed the nation's lands. But land management is typically carried out by Federal, State, and local agency personnel, zoning administrators, local planners, legislators, and private citizens with a wide range of academic and nonacademic backgrounds. To implement policies, they must understand them. Often success in implementation is inversely related to the complexity of the implementation approach.

Third, classifications should be linked to features capable of location on the ground by relatively untrained personnel (wherever possible). Critical area experience indicates that the precise location of zone boundaries is often a major issue and occupies much of the time of the regulatory administrator. Areas are best defined in relationship to identifiable features such as topographic contours, slope, dominant vegetation, or, in some instances, soils. Scientific nicety must, in some instances, be secondary to administrative needs.

Fourth, areas must be mapped at relatively large scale for urbanizing, urban, and other development areas. You may wince at the task of mapping at a scale of 1 inch equals 200 feet (2.5 cm equals 60.9 m) or 1 inch equals 2,000 feet (2.54 cm equals 609.6 m) on a national basis. But why conduct an inventory if it cannot be used for implementation? This scale of mapping is not needed for the country as a whole.

Scale and resolution of maps and aerial photos have sometimes been overdone. There is no legal requirement that areas be located with mathematical precision. Mapping of habitat and other resource lands creates a problem since boundaries cross lot lines and are not readily identifiable with reference to cultural features, such as roads which are typically followed by traditional zone boundaries. However, natural resource zones do not have precise demarcations and the actual resource rather than some classification scheme is the ultimate test for reasonableness of regulation or applied to particular land.

Most critical area regulatory efforts use a two-step procedure for determination of zone boundaries which could be applied to a habitat inventory. First, areas are given a written definition. For example, tidal wetlands may be defined with reference to tidal action and dominant vegetation. Second, areas are mapped at an intermediate scale, let's say 1 inch equals 1,000 feet (2.54 cm equals 304.8 m). In case of a boundary dispute, the regulatory permit officer makes a specific determination of zone boundary location based upon the written criteria and site-specific data gathering. This approach has been judicially approved.

Fifth, detailed air photos and raw data should be made available to land managers to facilitate more precise location of zone boundaries and case-by-case evaluation of development. Any national habitat classification and land inventory effort cannot hope to provide all of the information required for site-planning, environmental impact analysis, and evaluation of individual proposed developments. The gathering of very specific data on a case-by-case basis is needed to supplement such an effort. Often a portion of the information can be provided by developers. However, independent data gathering by the regulatory agency is also needed. Detailed air photos and raw data used in preparation of critical area maps (eg, wetland maps) can greatly assist these efforts. For site analysis, actual quantitative and qualitative measurements are important rather than abstract classifications. For example, for regulatory purposes it is initially useful to know that an area is an emergent coastal marsh. But one must know the depth, size, water quality, water regime, vegetation, slope, and other specifics to evaluate the impact of development.

Sixth, classification and inventory efforts should be designed to first address priority areas. If there is a single major lesson to be learned from state critical area programs, it is that priorities must be defined for data-gathering, regulation, and other implementation. Monies, manpower, and equipment are finite resources. Data gathering is expensive. For example, New Jersey spent $2.5 million mapping coastal wetlands. Failure to approach data gathering on a priority basis will often result in a dispersed and ineffective effort. The very concept of a critical area is based upon a recognition that all types of land and all areas cannot be studied and protected at once. Broadscale efforts to survey and manage all lands have usually resulted in small scale mapping of little use to regulatory and other implementation efforts.

Would a national habitat classification and inventory effort be funded at a level that would permit rapid survey of the country as a whole? Where would manpower and equipment be available?

If a national effort is to be undertaken, and I strongly support such an effort, the inventory begins by addressing priority types of areas such as wetlands, rare and endangered species, and areas of natural diversity. Let the survey personnel also address threatened areas such as urban fringes, lakeshores, and coastal sites and consider the willingness of states and localities to make immediate use of the information.

For efficiency, the survey effort should strongly involve states and localities to tap the enormous amount of information available from agency personnel, academics, and interested citizens. For example, people who have lived on or managed state park, wildlife, and scientific areas for many years often know a great deal about wildlife habitat, sites of rare and endangered species, and areas threatened by development. Time-series information and cultural information, such as land ownership needed for management efforts, cannot be readily extracted from an air photo or rapidly gathered through field surveys. Working with states and localities can be frustrating and takes special effort. But states and localities must be familiar with a classification and inventory to use it in their programs.

SOME FINAL REMARKS

I would like to summarize recommendations for a national habitat classification and inventory effort:

(1) First, consider management needs including sensitivity and threat. Put out a simplified version of the classification system which can be understood and used by laymen.

(2) Second, develop high resolution air photos, where presently not available, for use by states and localities as well as the national inventory.

(3) Third, prepare a "how to do it" manual for classification and inventory and distribute them to the states and localities. Carry out the actual inventory at reasonable scale with first priority upon urbanizing, coastal, and shoreland areas.

(4) Fourth, focus upon priority habitat such as (a) wetlands, (b) rare and endangered species, and (c) areas of natural diversity. These areas are of primary concern to state and local land management efforts. Do not let the forest obscure the trees.

(5) Fifth, involve states and localities. They need your help and have something to offer you.

(6) Finally, get on with it. Put a classification scheme together, test it for a year or so, and get on with the inventory.

SELECTED ABSTRACTS

A considerable body of literature has been developed concerning individual types of critical areas (eg, coastal areas, floodplains, etc.) but there is little literature concerning the broader context of critical area definition, standard-setting, and management. The following materials broadly address critical areas including their definition and data gathering needs.

Bosselman, F., and D. Callies. 1971. The Quiet Revolution in Land Use Control. Counc. Environ. Quality, U.S. Govt. Printing Office, Washington, D.C.

Excellent description of several of the better known floodplain, shoreland, wetland, and coastal area programs.

Hill, D. and H. Thomas. 1972. Use of Natural Resource Data in Land and Water Planning. The Connecticut Agric. Exp. Stn., Bull. 733, New Haven.

Excellent discussion of resource data and its uses but limited discussion of critical areas per se.

Jones and Stokes Associates, Inc. 1974. Development Guidelines for Areas of Statewide Critical Concern., Vols. 1 and 2. State of California Office of Planning and Res., Sacramento.

Good discussion of the development standards which might be applied to particular types of areas; matrices for development standards.

Niemann, B.J. 1974. Recommendations for the Assessment, Inventory and Implementation of a Critical Resource Information Program (CRIP) for Wisconsin. Univ. Wisconsin, Inst. Environ. Studies, Madison.

Extensive discussion of the values individual types of areas serve to society; focus upon data gathering and the definition of areas rather than subsequent management; matrices proposed for definition of areas. Good set of supporting documents, bibliography.

Smithsonian Institution. 1974. Planning Considerations for Statewide Inventories of Critical Environmental Areas: A Reference Guide. Center for Natural Areas, Office of International and Environmental Programs. Prepared for the U.S. Army Corps of Engineers, Washington, D.C.

Step-by-step approach proposed for the definition of critical area; focus upon data gathering and definition rather than subsequent management. Good appendix describing state definition efforts and selected data gathering program.

Thurow, C., W. Toner, and D. Erley. 1975. Performance Controls for Sensitive Lands: A Practical Guide for Local Administrators. Am. Soc. of Planning Officials, Planning Advisory Ser. Rep. 307.

Excellent general discussion of sensitive areas and local regulatory approaches; examples of local regulations.

Session II
Classification Systems

THE DILEMMA OF STREAM CLASSIFICATION

Robert W. Pennak[1]
EPO Biology
University of Colorado
Boulder, Colorado 80309

Abstract: Seven distinctive lotic categories may be designated for the U.S.A.: springbrooks, tundra brooks, mountain trout streams, sandy streams, and rivers of the Great Plains, medium to large silted rivers, sewage pollution stretches, and irrigation ditches. Each category includes lotic habitats that are remarkably similar from one part of the country to another.

All of the many other kinds of lotic habitats or stretches are grouped together as indistinctive, chiefly because they are so highly variable from place to place and because they defy practical classification. They do not conform to any published single-criterion or several-criteria systems. It is therefore recommended that such waters be characterized by means of a larger cluster of physical and chemical measurements: width, flow, current speed, substrate, summer temperatures, winter temperatures, turbidity, total dissolved organic matter, total dissolved inorganic matter, water hardness, dissolved oxygen, rooted aquatics, and streamside vegetation. Any two lotic stretches that are similar with reference to these features will have parallel groups of genera and species in their biotic communities.

INTRODUCTION

Although lake classification systems leave much to be desired, we nevertheless find common agreement on certain principles which have been generally adopted and refined during the past 50 years of limnology. Three examples should suffice; first, the oligotrophic-mesotrophic-eutrophic series is a familiar and broad concept. Second, the manner of classifying lakes according to their temperature regimes, especially as expanded by Hutchinson (1957), is extremely useful. A third method is based on the generic and species makeup of the benthic dipteran larvae; this concept has been variously developed by limnologists (eg, Brundin, 1949), but is seldom used in North America (Saether 1975).

Lotic classification systems, on the other hand, are highly unsatisfactory, especially when we attempt to apply them outside of small circumscribed areas where they are conceived, evolved, and applied. In a general way, the oligotrophic-mesotrophic-eutrophic terminology is occasionally applied to streams, but with little justification or supporting evidence. Unfortunately, we do not even have a precise way of distinguishing between the brook-creek-stream-river series.

In contrast to the physical-chemical-biological unity and the persistent and pervasive identity of a lake ecosystem, most streams consist of a longitudinal series of different alternating but intergrading communities and habitats. For example, one portion of a trout stream may consist of turbulent water with a rubble substrate. Five kilometers downstream the current may be relatively sluggish, and the bottom may be sandy or muddy with a growth of rooted aquatics. Another 5 km downstream a streamside town may empty inadequately treated sewage into the water, resulting in a completely different bottom fauna and water chemistry.

---

[1] Contribution 74, University of Colorado Limnology Laboratory.

It is therefore often inaccurate to categorize or pigeonhole streams or rivers, regardless of criteria, because of ecosystem differences along their courses. With certain notable exceptions, therefore, we shall speak of the "stretch" as the spatial ecological unit of streams and rivers. A stretch, having a certain group of chemical, physical, and biological characteristics, may thus be 30 m long and only a small part of a stream or river, or it may be 200 km long and comprise all or much of an extensive lotic continuum. Most important, we shall try to discuss criteria which might be used for identifying particular (and similar) stretches or habitats from one drainage to another, even though these may be widely separated.

It is not our purpose to provide a literature review of the problems of classifying lotic habitats. This purpose has recently been served by the material by Illies and Botosaneanu (1963) in several chapters of Whitton (1975). Both of these works have a strong European slant. Rather we shall suggest alternative approaches. Our emphasis will be confined chiefly to small rivers, streams, and brooks, especially as we think of these waters in the 48 contiguous states.

DISTINCTIVE LOTIC CATEGORIES

As we look at lotic habitats on a countrywide basis, we can identify seven lotic types which are distinctive and have relatively homogeneous and constant features from place to place, or which are especially typical of major geographic sections of the United States. Each of these is briefly characterized in the following sections.

SPRINGBROOKS

One of the most homogeneous and generally distributed lotic habitats is the springbrook. Although volume of flow may range from only a trickle to massive, their characteristics are otherwise remarkably constant. Usually a springbrook stretch is short, and customarily from source to its mouth in a stream or river the usual length is 10 to 100 m. If the channel is unusually long, then the brook loses its characteristic biotic community and becomes a stretch of another kind. The substrate is clean sand (especially near the source) to organic mud (downstream). Almost invariably there is a thick growth of watercress (*Rorippa*). Temperature is relatively constant and, depending on the location, does not vary more than a few degrees during a year. Mean temperatures range from 7°C to 15°C in most springbrooks.

The animal community almost invariably consists of a species each of planaria, amphipod, aquatic isopod, snail (*Physa*), and a seed clam. In addition to these dominant forms, there are usually a few aquatic dipteran larvae, beetles, caddis larvae, mayfly nymphs, and leeches, but these less abundant forms seldom account for more than 5 percent of the total animal biomass. Occasionally small fish are seen in springbrooks; these are vagile species (usually cyprinids) native to the stream or river into which the springbrooks empty.

TUNDRA BROOKS

Very little has been published on the ecology of permanent brooks found above altitudinal timberline. In general, they are strikingly similar from one place to another over the entire Rocky Mountain area. Usually they are less than 2 wide and less than 20 cm deep, but the flow is variable, depending on the intensity of snow melt and showers. Temperature seldom gets above 8°C and during most of the year the temperature ranges between 0°C and 4°C. Total dissolved solids are commonly below 30 mg/l. The substrate consists chiefly of boulders and rubble, with little gravel or sand. Lithophyton is poorly developed, primary production is low, and the fauna consists almost entirely of chironomid larvae, with only an occasional simuliid, caddis larva, mayfly nymph, and stonefly nymph (Elgmork and Saether 1970). Some tundra brooks contain populations of cutthroat trout (_Salmo clarki_) or rainbow trout (_S. gairdneri_), and occasionally these fish grow to astonishing size, considering their restrictive habitat.

Tundra brooks in the flat terrain of high latitudes are ecologically quite different from our low-latitude mountain tundra brooks.

MOUNTAIN TROUT STREAMS

Beginning at timberline and extending down to elevations of about 2,000 to 1,500 m is a mountainous area characterized by growths of pines and spruces. This is the high-gradient valley zone of mountain trout streams found in an irregular pattern between the West Coast and the 110th meridian in Montana, the 108th meridian in Wyoming, and the 105th meridian in Colorado and New Mexico. Homogeneous stretches may be more than 50 km long; others may be frequently interspersed with other kinds of trout stream stretches. Comparable small areas are also found in the Appalachians, sometimes as low as 1,200 m in altitude. Mountain trout streams differ from each other most obviously in width and depth, but otherwise they are remarkably similar. The substrate is chiefly rubble. There is great turbulence and more or less white water. Dissolved oxygen is always near 100 percent saturation. Temperatures are low during much of the year and seldom exceed 15°C in midsummer. Waters range from soft to hard; hydrogen-ion concentration is almost invariably above pH 6.8; total dissolved solids depend upon distance from source, time of year, volume of flow, and local geochemistry.

The bottom fauna consists chiefly of Diptera, Ephemeroptera, Plecoptera, and Trichoptera, and in most streams of the West the standing crop is "poor" (less than 11 g/m^2 wet weight). Species composition varies with altitude and latitude, but the generic composition is remarkably homogeneous. Many species show definite altitudinal patterns. Hynes (1970) maintains that among lotic habitats worldwide, it is only the smaller stony streams that have a truly distinctive fauna. His "stony streams" include my category of tundra brooks and mountain trout streams.

Mountain streams characteristically have heaviest flows during the spring runoff, but additional spates may occur at any time during the warm months as the result of localized heavy rains or cloudbursts. These heavy flows have a scouring effect, but it is remarkable to see how rapidly the bottom fauna recovers from its losses.

Periphyton is highly variable and ordinarily lowest shortly after spring runoff. Except for a few aquatic mosses, there are no growths of macrohydrophytes.

Depending on the locality, the dominant carnivorous fish is the rainbow, brook (Salvelinus fontinalis), cutthroat, or brown trout (Salmo trutta), each of which should be capable of maintaining itself as a continuing natural population if the stream is to qualify as a "mountain trout stream."

There are many stretches of lowland streams in the northeastern States that might qualify marginally as "mountain trout streams" because they pass through conifer forests and because they have persistent trout populations. Ordinarily, however, such stretches are short and they have relatively low gradients throughout most of their lengths, so that white water areas are restricted and scattered. In addition, maximum summer temperature may often reach 18 to 21°C, and there are frequent growths of rooted hydrophytes.

There are also many high altitude Western trout stream stretches that do not qualify as "mountain trout streams" because they may have low gradients, brush shorelines, and may traverse arid valleys or open meadows and ranch land.

SANDY STREAMS AND RIVERS OF THE GREAT PLAINS

The flat or gently rolling terrain, known originally as the short-grass plains, extends eastward from about the 96th meridian to the base of the Rocky Mountain foothills, and from Montana and North Dakota southward to Texas. Most of the streams and rivers in this vast area fit into a relatively homogeneous category. Even from a distance, they are often distinguished by a border of cottonwood trees (Populus). They are shallow, relatively broad, with a braided channel, and a sandy substrate containing variable quantities of silt and mud. Sometimes there is a thin to thick mat of filamentous and unicellular algae on the surface of the substrate, especially during months of low flow.

The water chemistry of Great Plains streams is highly variable, depending on distance from headwaters, season of the year, and local geochemistry of the substrate. Some of these streams are high in carbonates (very hard--more than 100 ppm bound CO_2). Others are characterized by their high sulfate content (rarely chloride content).

MEDIUM TO LARGE SILTED RIVERS

Many medium to large rivers in the United States can be assigned to another category characterized chiefly by their permanent silted condition, including such examples as the lower portions of the Mississippi, Ohio, Missouri, Colorado, Monongahela, Rio Grande, Wabash, Arkansas, and Yampa. Such waters are comparable and notable for their many kilometers of homogeneous qualities. They are deep to shallow (but not as shallow as rivers and streams of the Great Plains). Portions of these larger rivers are often more or less polluted by domestic, industrial, and agricultural wastes. Substrates are composed of organic and inorganic silt. The current is slow, there is little autochthonous primary productivity, and the bottom fauna ranges from sparse to occasionally high densities of herbivore and detritivore insects (especially mayflies and dipterans). The catfishes (Ictaluridae) are usually regarded as the most important "game" fishes, and there are also populations of Catostomidae and Cyprinidae. Carnivorous fish, such as the Centrarchidae, Percidae, and Esocidae, are notably uncommon or absent.

SEWAGE POLLUTION STRETCHES

Thousands of raw or partially treated sewage effluents produce a consistent type of stream and river stretch almost everywhere, especially if the dilution factor is not too high. Indeed, this whole situation is now such a familiar part of the literature of aquatic ecology and sanitary engineering that only a brief characterization is necessary here.

Depth, width, and substrate of a polluted stretch seem to be of little consequence, but depending on the volume of effluent and the relative intensity of pollution, the length of the stretch before self-purification has completed its cycle may be 200 m or it may be as much as 200 km. Between the sewage outfall and the end of the polluted stretch there is a characteristic sequence of bottom organisms. The short zone of degradation has none of the "normal" (upstream) species, and only a few pollution indicator species. In the zone of active decomposition, however, where the oxygen concentration often falls to zero percent saturation, the typical "sewage biota" takes over, sometimes in enormous densities: rat-tailed maggots, chironomid larvae, tubificid worms, protozoans, and masses of pollution fungi. In the "zone of recovery" where the oxygen concentration builds up from 40 or 70 to 100 percent saturation the sewage biota disappears, and a rich alternate bottom fauna takes over. It is featured by a dense population of snails (Physa), leeches, planarians, isopods, amphipods, and many insects. By the time stream enters the "clean-water" zone, the excess dissolved nitrates, phosphates, and other important nutrients have largely disappeared, and the stream assumes essentially the same features it had just above the outfall.

IRRIGATION DITCHES

Those who live in the humid eastern states usually do not appreciate the many thousands of kilometers of essential manmade irrigation ditches and canals that blanket so much of the 11 Western states. Purely on the basis of the magnitude of these operations, I feel (with reluctance) that I must designate irrigation channels as a seventh kind of distinctive lotic habitat.

Most ditches are less than 2m wide, the vast majority are variable and intermittent, and there is no white water. Otherwise they have little in common. Temperature, substrate, and water chemistry, for example, are highly variable. There is no irrigation ditch community except for those few species of insects and microzoans that may survive variable dry periods. However, there sometimes is a sparse "drift" fauna originating at the headgate.

OTHER DISTINCTIVE LOTIC CATEGORIES

Strictly speaking, there is no reason why we should stop at only seven categories of distinctive lotic habitats. There are many others that are widely distributed over the United States, but these are mostly "anomalous," highly artificial, manmade, or represent only minute fractions of the total lotic environment. Some examples are: acid-mine waste streams, marl streams, hot spring effluents, tail waters of hydroelectric plants, streams just below high storage dams, oil polluted waters, and "dead" waters. The last of these categories includes sluggish waterways, harbors, and dockage areas that are hopelessly polluted by various toxic substances and have been biologically sterile for many years.

INDISTINCTIVE LOTIC HABITATS

After all of the foregoing, we are left with a wide variety of lotic situations unaccounted for, such as: intermittent streams, desert streams, streams traversing agricultural lands, meadow brooks, stretches through towns and cities (with all their associated trash), sluggish waters of Florida and the Gulf Coast, "bass streams," streams that traverse many miles of suburbia, streams of the hardwood-forested hills, canals, swamp flowages, and brackish stretches.

These waters differ from each other in a hopelessly intergrading and haphazard fashion, and in all manner of physical, chemical, and biological features. We do not see how any one group can be characterized as being a consistent category from one part of the country to another.

Before commenting on our own recommendation for classifying these many different waters, however, we should like to note several classification schemes that have appeared in the literature since 1908.

The great majority of systems are of European origin and are based on single criteria or clusters of two to four criteria. These are reviewed by Illies and Botosaneanu (1963) in Whitton (1975), and only a few will be briefly mentioned here. In Germany, Wales, Italy, France, and eastern Europe various classifications have been based on the one typical (or dominant) species of fish per stream category, in some cases with supplementary brief characterization of volume of flow and species lists of bottom invertebrates. Four or five such fish zones are designated from headwater brooks to the upper limit of tidal waters near sea level. In other parts of the world such schemes have been proposed for parts of Africa, South America, and New Zealand. Similar fish-oriented classifications have been described for several small and localized drainages in Illinois, Virginia, and Missouri.

For running waters in the United States, on a wide geographic basis, we have no confidence in such classifications based on single "characteristic" species of fish. Recall, for example, the wide variety of American running waters where catfish are the obvious dominant. Or visualize the same generalization for "cyprinid" streams, trout streams, or smallmouth bass streams.

The distribution or zonation of bottom invertebrates has been studied in a great many localized drainage systems in many parts of the world in an attempt to find some underlying schematic principles. Almost invariably it is possible to demonstrate a different altitudinal and longitudinal distribution pattern for each species, but the results are of limited application because of wide faunal differences in streams from one part of the country to another. May we suggest, however, that a careful and massive study of the lotic chironomid distribution in the United States may result in a usable stream typology analogous to the lake chironomid typologies for Europe (Brudin 1949, Saether 1975).

Essentially all of the routine chemical and physical features of lotic habitats have been unenthusiastically suggested for single-criterion classification schemes by various investigators: current, volume of flow, substrate, temperature, dissolved oxygen, calcium content, and stream ordination. None of these have attracted much attention. Biologically, and from the available evidence, it does not appear that plankton (pseudoplankton) and periphyton (Pennak 1977) can be of practical use in classification systems.

The single-criterion basis of stream classification receiving the most credence and attention, especially in Europe, is the saprobic system, first proposed in 1908 but more recently debated and modified many times. A widely accepted version has been presented by Fjerdingstad (1965). This is a system of judging running waters according to the amount of organic matter, as determined by biological oxygen demand. Zone I (grossly polluted) of a river may be "coprozoic" and have typically in excess of 100 ppm BOD. At the other extreme, Zone IX (katharobic) waters are the cleanest surface waters with a BOD of ≤ 1 ppm. The saprobic system is most useful in determining the degree of organic pollution but, as such, does little to distinguish between stream types.

Multicriteria methods of classifying lotic habitats usually are based on the determination of a combination of several to many physical, chemical, and biological factors in a stretch of water. The most pertinent and widely quoted scheme in North America is that of Ricker (1934) for streams in Ontario. He uses a combination of flow, width, temperature, substrate, current, vegetation, hardness, and dominant bottom fauna and fishes. A similarly useful scheme, on a local basis, is that of Van Deusen (1954) for streams in Maryland. Illies and Botosaneanu (1963) divide streams into eight altitudinal (and temperature) zones from source to mouth at sea level; each zone has its characteristic families of aquatic insects.

The labor and time involved in calculating primary production, secondary production, and energy budgets in lotic stretches make it difficult to use these devices for classification schemes.

What can we say about a suitable stream classification for indistinctive lotic habitats or stretches in the United States, in the light of our discussion thus far?

It is obvious that we are dealing with an enormous variety of running waters where there are wide ranges of chemistry, physical qualities, and biological details, and where single-criterion and several-criteria systems are of limited coast-to-coast value. We should therefore like to suggest that the 13 criteria listed a few years ago (Pennak 1971) should be seriously considered for characterizing indistinctive stretches. These criteria are: width, temporary or permanent flow, current speed, substrate, summer temperatures, winter temperatures, turbidity, total dissolved inorganic matter, total dissolved organic matter, water hardness, dissolved oxygen, rooted aquatics, and streamside vegetation.

While this might appear to be a long and difficult list, each feature can be determined with relative ease. Furthermore, as emphasized in my earlier paper (Pennak, 1971), when two widely distant stretches of streams are found to have similar chemical and physical features, then the biotic communities will be found to have parallel clusters of species and genera occupying corresponding niches, even though the relative densities of the bottom forms may differ greatly in the two localities. Admittedly, this is a highly artificial and nontaxonomic means of classifying indistinctive lotic habitats, but until some better schemes evolve, we shall have to resort to these character-descriptive devices.

LITERATURE CITED

Brundin, L., 1949. Chironomiden und Andere bodentiere der Südschwedische Urgebirgsseen: Ein Beitrag zur Kenntnis der Bodenfaunistischen Characterzüge schwedischer oligotropher. Seen. Rep. Inst. Freshw. Res. Drottningholm 30: 1-914.

Elgmork, K., and O.R. Saether. 1970. Distribution of invertebrates in a high mountain brook in the Colorado Rocky Mountains. Univ. Colo. Studies, Ser. Biol. 31: 1-55.

Fjerdingstad, E., 1965. Some remarks on a new saprobic system, pp. 232-235. In Biological Problems in Water Pollution, Third Seminar, 1962. U.S. Public Health Serv. Publ. 999-WP-25.

Hutchinson, G.E., 1957. A Treatise on Limnology. Vol. 1. Geography, Physics, and Chemistry. New York, N.Y., 1,015 pp.

Hynes, H.B.N., 1970. The Ecology of Running Waters. Toronto, Canada, 555 pp.

Illies, J., and L. Botosaneanu, 1963. Problèmes et méthodes de la classification et de la zonation écologique des eaux courantes, considerées surtout du point du vue faunistique. Comm. Int. Assoc. Theor. Appl. Limn. 12: 1-57.

Pennak, R.W., 1971. Toward a classification of lotic habitats. Hydrobiologia 38: 321-334.

Pennak, R.W., 1977. Ecological variables in Rocky Mountain trout streams. Arch. Hydrobiol. (in press).

Ricker, W.E., 1934. An ecological classification of certain Ontario streams. Univ. Toronto Stud., Biol. Ser. 37: 1-114.

Saether, O.A., 1975. Nearctic chironomids as indicators of lake typology. Verh. Int. Ver. Limnol. 19: 3127-3133.

Van Deusen, R.D., 1954. Maryland Fresh-water Stream Classification by Watersheds. Contr Chesapeake Biol. Lab. 106: 1-30.

Whitton, B.A., (ed.), 1975. River Ecology. Berkeley, California, 725 pp.

LAKE CLASSIFICATION—GOOD AND BAD

Gerald A. Cole
Department of Zoology
Arizona State University
Tempe, Arizona 85281

Abstract: Throughout the history of limnology there has been much concern with lake classification and systematizing. Most categories that have been proposed do not apply on a worldwide basis and are vitiated by regional factors. Lake classifications have been based on at least: geologic origin, edaphic factors, geographic and hydrologic features, trophic status, water chemistry, annual circulation patterns, the morphoedaphic index, and complex taxonomic schemes involving chemical, geographic, morphologic and biotic elements. It is suggested that classification of lakes should be founded on assay at the regional level, but with comparative reference to relevant categories elsewhere.

INTRODUCTION

I remember, when I was first learning limnology, looking back to fundamentals in the literature and find the experience most discouraging indeed. Would I ever know enough to recongize Lehmgyttja and to distinguish it from Feindetritusgyttja, despite the good photographs offered by Lundquist (1927)? Would I ever attain some sort of competency in deciding which pigeonhole a lake should occupy out of the array of 20 or so listed by Naumann (1932)? Would I recognize siderotrophy, if I fell over it? The answers to these questions were not encouraging.

The literature sources mentioned above came from the flowering of lake typology and early comparative regional limnology, subjects that had their beginnings toward the end of the first decade of this century (Thienemann 1909) from a simple nutrient-in-water classification devised by Weber (1907). These subjects picked up steam during the second decade (eg, Naumann, 1917, 1919) and were really going strong in the third decade, gaining momentum to such an extent that the major topic of the 13th Congress of the Societas Internationalis Limnologiae in 1956 was Seetypenlehre. And here we are now--still concerned with habitat classification.

Out of the early lake typologists' attempts to categorize, grew regional limnology and, in my opinion, this is still of paramount importance in systematizing lakes in terms of fish or wildlife habitat with emphasis on the former.

The goal of the young science of limnology was to build a taxonomic framework into which bodies of water would fit and from which would emerge a pattern revealing widely applicable generalities. The result was something akin to a group of shoe sizes into which different feet fit. Sometimes it is a comfortable fit, but often the pinch is painful, and there are times when the foot cannot be jammed into any category no matter how we try. Yet, even today worried people write papers concerned with the difficulty in assigning a trophic status to some lake (eg, La Perriere, et al. 1975).

Some generalities that came from early endeavors in lake classification are verities (at least they appear to be from the 1977 viewpoint); others do not survive the acid test. But, on a regional basis, I think that useful categories can be found for describing fish and wildlife habitats. In North America, the next step should be regional classification of lakes, with a strong comparative flavor based on worldwide studies and standards. Thus, the efforts of state and provincial game and fish departments could lead to habitat classifications that are applicable regionally, even though far less serviceable elsewhere. This would not necessarily be turning back the clock. I hope to show that consistency sometimes becomes a foolish hobgoblin when limnology concepts from other regions are applied locally, and that aquatic ecologists should not be too concerned if simple categories are not quite adequate.

LAKE CLASSIFICATION PLANS

GEOLOGIC METHODS OF ORIGIN

The many ways by which lake basins come into being were brought together and explained by Hutchinson (1957). Since then a few other processes have been revealed. Now the phenomena known to be involved in the genesis of lakes total more than 80.

Beadle (1974) expressed his distrust of lake classification and pointed out how limnologists tend to force lakes into inappropriate categories. He made his point with an example of a body of water being branded eutrophic because of severe oxygen depletion in a relatively tiny hypolimnion despite the lack of dissolved nutrients and a low primary productivity. It is noteworthy, however, that Beadle discusses the lakes of Africa very much in terms of their origin, arranging them as rift lakes, volcanic lakes, etc. The method of origin is useful systematics on a regional basis, and general patterns emerge from which one can describe aquatic habitats in Africa.

Contradictions appear, however, when an alkaline East African volcanic lake is compared with some lakes reported from Central America with pH values as low as 2.0 (Armitage, 1958). Other Central American crater lakes have extremely high pH, reminiscent of the African waters. Hydrogen-ion concentrations represented by pH less than 4 and above 10, however, may eliminate any ichthyofauna. Something, then, can be said about both extremely acid and basic waters as habitats, and some volcanic crater lakes should be viewed with suspicion, for example, in fish-stocking programs.

THE EDAPHIC FACTOR

Very closely related to the geologic origin of lake basins is the substrate, the so-called edaphic factor. The availability of nutrients that lie at the heart of primary productivity and, ultimately, the nature of the body of water as a habitat, is mostly a function of the lithology and soils of the surrounding terrain. This seems obvious and trite, but there are pitfalls in accepting this completely. Jarnefelt (1956) pointed out that eutrophic lakes may lie in oligotrohic soils and vice versa, because of the influence of distant lands via allochthonous import. Despite this, from a regional standpoint, classifying lakes as wildlife habitats on the basis of soil surroundings can be useful. To me, Moyle's (1945, 1956) treatment of Minnesota edaphic regions is an excellent example. There are mainly three distinct soil types in the state owing to three different geological histories. Terrestrial vegetation, water quality, and lacustrine biota are correlated with the substrate. Thus, the lake trout (Salvelinus namaycush) occurs in ice-scoured basins in granitic soils to the northeast; the carp (Cyprinus carpio) is present especially in sulfate waters in southwestern Minnesota, once covered by Cretaceous seas. Classification of wildlife habitats at the state level according to edaphic factors is valid and rewarding in Minnesota. Parenthetically, Moyle's survey of the State on the basis of fundamentals--water chemistry for example--probably got to the heart of matters more efficiently than did earlier surveys where plankton samples were amassed and analyzed.

GEOGRAPHIC LOCATION AND HYDROGRAPHIC GROUPINGS

Geographic designations of lakes came about very early in limnology when relatively few data had been accumulated. It was believed that there were two fundamental types of lakes: caledonian-subalpine and baltic lakes (Thienemann 1909, Teiling 1916). This scheme began to disintegrate after Thienemann (1915) found midge larvae belonging to the genus Tanytarsus, typifying the bottom fauna of deep subalpine lakes, and those referable to Chironomus, an indicator of the baltic type, in two adjacent German lakes separated only by a ridge (Rodhe, 1975).

On a limited regional basis, however, the geographic concept is good. In Arizona, the physiographic provinces and their aquatic habitats are distinct. In Minnesota, the geographic designations would follow edaphic zones. On a slightly broader basis, one might expect geographic classification to be useful, for example, to differentiate lakes of different parts of New England.

A good portion of the North American continent is prairie or desert, and in such regions, if there is a net evaporation, closed lake basins may occur. Actually, it is difficult to find good examples in climates where the net evaporation is < 25 cm per annum. The closed basins identify desert limnology, even though many lie in steppe areas or in a savannah-like parkland.

Typically the lakes are saline and not noted for good commercial or sports fisheries, although very high fish yields can come from managed desert ponds. In Arizona, some dilute natural lakes near Flagstaff are an exception; they have been deepened somewhat and they seem to stay fresh because of the porous nature of their volcanic-ash substrates--or so it is conjectured. Saline, closed basins contain a large number of fish species with high annual productivities, in parts of Africa, where these lakes have had entirely different geologic, climatic, and evolutionary histories. Closed basin is a nice category, but one must know the local situation before generalizing.

In regions where the annual net evaporation surpasses 100 cm, i.e., where the mean annual temperature is at least 15°C and is accompanied by precipitation most waters are temporary. The exceptions are those basins receiving subterranean water or supplied by large rivers that arise elsewhere. In the case of artificial lakes in such climatic zones, and especially those formed by impounding large rivers, the water is relatively fresh because there is an effluent; their basins are not closed. It turns out that in Arizona, where the yearly net evaporation may surpass 200 cm, good fishing spots are almost entirely restricted to streams and artificial lakes.

Open lakes are found where the ratio of annual evaporation to yearly precipitation is $\leq$ zero. Rivers arising in such climatic regions ultimately reach the sea. The great majority of limnologic studies have dealt with open lakes in humid zones.

ARRANGEMENT ACCORDING TO TROPHIC STATUS

Geographic terms for lakes were replaced by the broader adjectives, eutrophic and oligotrophic (Naumann 1919), words coined 12 years earlier to describe waters rich in and poor in plant nutrients respectively (Weber 1907). The baltic types were eutrophic; the caledonian and subalpine lakes were named oligotrophic. Later came dystrophic (Thienemann 1925) and then a bewildering array of terms and combinations of terms (Naumann 1932): alkalitrophy, argillotrophy, azidotrophy, orthotrophy, paratrophy, mixotrophy, and sidetrophy. More have been brought into the world since then! As authors discussed the various trophic states, they strayed far from the original meanings of eutrophy and oligotrophy. At first one could describe a small sample of water as one of the two without reference to oxygen profile, fish in the hypolimnion, genera of profundal midge larvae, or light penetration. As the definitions were compounded, sometimes they became less useful in instances where it was desirable to place a lake in a specific category. Occasionally, however, a name from past literature serves, unexpectedly, to tell us something about a lake. Thus the term chronio-eutrophic, coined 20 years earlier to describe some Finnish lakes (Jarnefelt 1956) was applied by Nordlie (1976) to Newnan's Lake near Gainesville, Florida.

A relatively new adjective, hypereutrophy (Wetzel 1966), is useful with all the phenomena it describes. It refers to an extreme category. Otherwise the old standards, eutrophy and oligotrophy, must be employed with care while guarding against slipping across boundaries between primary eutrophy-oligotrophy and secondary eutrophy or oligotrophy. It would be valuable, however, to employ certain meter sticks from other regions in classifying lake habitats, using the "troph" words. For example, one might report that the waters of a lake district contain, on the average, 0.065 mg total phosphorus per liter, falling well within the eutrophic category proposed by Vollenweider (1968).

For several decades, autotrophy and allotrophy have served as two main groupings for lakes, indicating whether their organic compounds are produced in situ or come from external sources. This has been more important in the field of lotic limnology, where allotrophy is equated with heterotrophy and the photosynthesis/respiration ration (P/R) has been used widely, perhaps because heterotrophy-allotrophy is more important in streams. Beadle (1974: 88) mentioned two African lakes, ranking high in fish and invertebrate productivity, that are strongly allotrophic, and several earlier authors pointed to allotrophy in dystrophic lakes of northern Europe (Rodhe 1969). The P/R ratio could be very useful regionally, where bodies of water might fall naturally into groups with values 1.0, <1.0 and >1.0.

A fundamental approach to the trophic classification of lentic habitats hinges on the rate at which carbon is fixed by lacustrine photosynthetic organisms. Rodhe (1969) presented some approximate ranges for oligotrophic, naturally eutrophic, and polluted lakes, extending from 7 to 700 g C/m^2 per year. The ranges do not apply everywhere and, once again, regional discrepancies come to light. For example, unpolluted desert or tropical lakes may exceed the rate Rodhe suggested for polluted bodies of water.

In addition to allocating lakes according to the rate of carbon fixation, other plans have been used to assign them to either the eutophic or oligotrophic category on the basis of the mass of chlorophyll a per m^3 or per m^2 . The presence of chlorophyll is, of course, closely linked to photosynthesis, and various amounts of the pigment have been somewhat arbitrarily related to trophic status. One of the most recent attempts was that of Margalev (1975) who used concentrations of chlorophyll a as part of a plan to categorize Spanish reservoirs.

MAJOR IONS AND WATER TYPES

Systematizing lake waters according to chemical composition is not to be overlooked, even though Kemp (1971) emphasized the importance of total dissolved solids rather than ionic proportions in classifying waters. Where edaphic substrates are varied, the grouping of lakes on the basis of ionic composition of their waters would be advisable even though the direct effect of relative ionic makeup on the biota may be slight when total salinities are relatively low and subequal. Certainly, comparative salinities should be taken into account when ionic compositions are used to categorize habitats, and at high salt concentrations, above 10 percent for example, the biotas of sodium-bicarbonate waters and sodium-chloride solutions are different. Classifying lake waters on the basis of relative ionic composition usually does not entail forcing them into categories they do not fit. Thus, Kubly and Cole (unpub. ms. 1976) found the Colorado River and its tributaries in Marble and Grand Canyons could be grouped into five categories following the distributions of the seven major ions. What this leads to in terms of discrete habitat differences the latter authors are not prepared to say; perhaps their additional data on total salinity and the plant nutrients, silica, phosphorus, and nitrogen are more important.

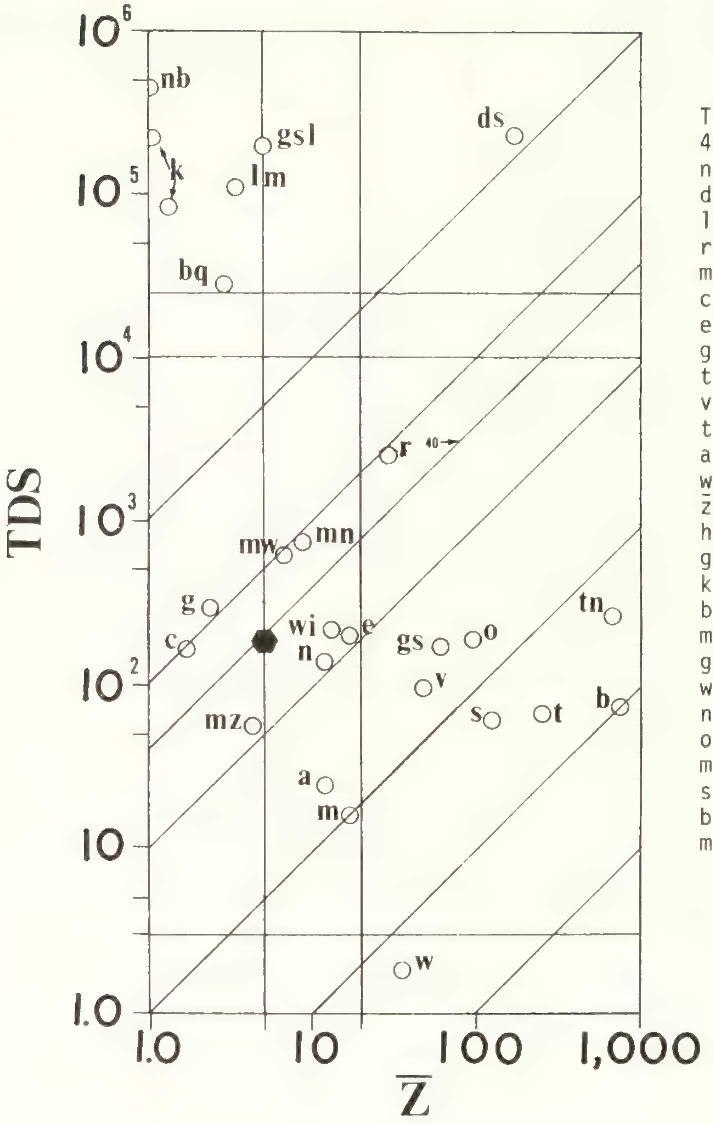
ANNUAL CIRCULATION PATTERNS

Schemes to arrange lakes according to their annual circulation patterns have been modified and improved over the years. Hutchinson and Loffler (1956) presented a plan that serves very well and in most regions lakes can be described using one of their groups. Bayly and Williams (1973) proposed further divisions to accommodate some Australian and New Zealand lakes, pointing out the lack of dimictic lakes in those nations even though dimixis is a textbook example of the annual temperature regime. There are many examples of lakes that fit more than one category, differing from year to year. People are still interested, however, in the typology of circulation patterns as witnesses by a recent paper by Walker and Likens (1975). They focused especially on meromixis and brought the subject up to date. Their classification of meromictic lakes, founded on phenomena making for a partial circulation, is good, but meromixis in a single lake is often due to more than one factor, blurring the boundaries between those authors' categories.

There must be many North American states and provinces where thermal-circulation classifications are unequivocal, and where they tell a good deal about the lake as a habitat. It is important, however, that other data are known: a small, shallow cold-monomictic lake might imply a winter fish kill as a regular event, its biota thereby differing from a deeper neighbor that is also cold monomictic.

THE MORPHOEDAPHIC INDEX (MEI)

Ryder's (1965) morphoedaphic index was discussed in detail by Ryder et. al., (1974), who presented material that is useful in the present paper. Figure 1 is based on Ryder et al. (1974: Figure 2) and can be used to show how certain environmental parameters bring about different results in different settings.



LEGEND TO FIGURE 1

TDS = Total dissolved solids in ppm
40 line = MEI of 40
nb = Nebraska Sandhill pond
ds = Dead Sea, Israel
lm = Little Manitou, Saskatchewan
r = Lake Rudolph, Kenya
mn = Managua, Nicaragua
c = Chad, French Equatorial Africa
e = Lake Erie, USA & Canada
gs = Great Slave Lake, Canada
tn = Tanganyika, East Africa
v = Lake Victoria, East Africa
t = Lake Tahoe, Cal.-Nevada
a = Anguish Lake, Ontario
w = Waldo Lake, Oregon
$\bar{z}$ = Mean depth in meters
hexagonal = Theoretical optimum
gsl = Great Salt Lake, Utah
k = Long-H ponds, Arizona
bq = Big Quill Lake, Saskatchewan
mw = Montezuma Well, Arizona
g = Lake George, Uganda
wi = Lake Winnipeg, Manitoba
n = Lake Nicaragua, Nicaragua
o = Lake Ontario, USA & Canada
mz = Lake Mize, Florida
s = Lake Superior, USA & Canada
b = Lake Baikal, Siberia
m = Moosehead Lake, Maine

Figure 1. A log-log plot of total dissolved solids (TDS) and mean depth ($\bar{z}$) for 26 lakes; each diagonal line represents the dimensionless morphaedaphic index (MEI = TDS/$\bar{z}$); horizontal lines represent important salinity thresholds, and vertical lines indicate important mean depths, discussed in text.

Figure 1 also shows two environmental restraints that either limit fish yield or preclude fish existence. The ordinations of certain lakes are such that one would expect (from the mean depth--total dissolved solids [TDS] intercept) them to produce fish. Other factors enter the picture, however, and are relevant in categorizing a body of water as a habitat.

First, according to Ryder et al. (1974), a morphoedaphic index (MEI) of 40--when the total dissolved solids, expressed in ppm, are 40 times greater than the mean depth in meters--is the optimum ratio. Near the interception of the 40 MEI line and the 5-m mean depth line there is a point of maximum potential yield, climatic effects not considered.

The MEI then could be an important thing to consider in the systematics of lakes. There are, however, some limitations and regional effects on such a concept (Figure 1). In north temperate regions, mean depths less than 5 m may portend winterkill beneath the ice, but Lake George, Uganda (Figure 1) is very productive despite a mean depth less than 3 m and, incidentally, an MEI of more than 100.

At about 18 m depth there is a point where morphologic factors cancel out favorable TDS concentrations and fish yields are lowered (Rawson 1952). This is shown when Lake Erie (Figure 1) is compared with the other Laurentian Great Lakes. Although productivity is not part of Figure 1, Lake Erie and, parenthically, Lake Winnipeg (Figure 1) have far greater annual fish yields. Contradictory data came first from Lake Nicaragua (Figure 1), falling on the plot near Erie and Winnipeg, but with a very low, not clearly explained, annual yield, and second from Lake Rudolph in Kenya (Figure 1) that produces some 300 kg/ha of fish each year (Beadle 1974) despite a mean depth probably > 18 m. Lake Rudolph's production is 30 times that of the north temperate lakes, Erie and Winnipeg.

Figure 1 shows restraints posed by both high salinity and extreme dilution. Waldo Lake, Oregon (Figure 1) with a mean of about 1.7 ppm TDS and an MEI of 0.04, is one of the world's most oligotrophic lakes, if we base the definition on nutrient content of the water. It is surprising that it is reported to support two salmonid and a cottid, because most plankton tows yield no zooplankton (Malueg et al., 1972). Near the top of Figure 1 are shown lines indicating the inhibition effected by too much salinity. Ryder et al. (1974) placed a horizontal line at 10,000 ppm, or one percent, to show the boundary above which ionic and osemoregulation is difficult for most stenohaline freshwater species. Bayly and Williams (1973) put the boundary between fresh and saline water habitats at 3,000 ppm, and Beadle (1974) put 5,000 ppm at the upper limit for tropical African freshwaters. The 100,000 ppm (10 percent) line applies to euryhaline invertebrates and plants; above this concentration species richness is much reduced. The 25,000 ppm (2.5 percent) line shows a boundary in Canadian waters between sparse ichthyofaunas and successful introductions of some freshwater fish just below the line, and no fish above the line. A certain Australian atherinid, however, has been taking in salinities 2.8 times this (Bayly and Williams 1974:204).

The extremely saline lakes, plotted in Figure 1 above 85,000 ppm, differ in ionic proportions. It is there that the physiologic and ecologic effects of mineral composition may come into play. For example, Utah's Great Salt Lake (Figure 1, gsl) and Israel's Dead Sea (Figure 1, ds) have similar total salinities. Their mean depths are very different and, as a result, the MEI of the former is about 40,000 and the Dead Sea's is near 1,500. The brineshrimp, *Artemia*, occurs in Great Salt Lake, but is absent from the Dead Sea. The reason for this probably has little to do with the MEI, mean depth, or total salinity. Great Salt Lake is a saltern, a sodium-chloride lake; the Dead Sea is a bittern with much magnesium chloride and bromide, both of which place severe stress on higher organisms.

Three other lakes are plotted in Figure 1 for the purpose of showing factors (other than salinity and mean depth) that play roles in precluding fish faunas. Montezuma Well (Figure 1, mw) an Arizona limnocrene occupying a solution basin, has a favorable MEI, contains calcium-bicarbonate water, and its annual primary productivity is high. Despite these features, it supports no fishes. Their absence is explained by the high level of free CO_2 in its waters, ranging to more than 500 mg/l (Cole and Batchelder 1969, Cole and Barry 1973). Although there is adequate dissolved oxygen to meet fish respiratory needs, the abundant CO_2 is the overpowering environmental factor to be considered when thinking of Montezuma Well as a habitat.

Lake Mize (Figure 1, mz) is a solution basin near Gainesville, Florida. Its ordination in Figure 1 suggests no unfavorable morphoedaphic factors. It is oligotrophic, as might be expected from its low TDS, and fixes a mean of only 0.07 g C/m^2 per day (Nordlie 1976). Because its water is deeply stained, Nordlie termed it chthonio-oligotrophic, following the terminology proposed for some Finnish lakes by Jarnefelt (1956). Surprisingly, it contains only one species of fish. This might be a function of its small area (0.86 ha) and steep sides, but another factor not to be overlooked is its low pH, ranging from 3.6 to 5.9 (Nordlie 1976).

Anguish Lake (Figure 1, a) is one of the acid-stressed La Cloche Mountain lakes near Sudbury, Ontario. Its pH is presently 4 and it no longer contains fish (Harvey 1975). From its position on the morphoedaphic plot, one would expect it to be oligotrophic but certainly not devoid of fish. Nearby on the graph is New England's largest lake, Moosehead (Figure 1, m), which has many species of fish. Hydrogen-ion concentrations in poorly buffered waters are a modern problem. When pH values fall, approaching 4, most fish species, to say nothing of the molluscs, are in trouble.

Toward the other end of the scale, a threshold seems to be approached when pH values reach 10. Many alkaline lakes are also extremely concentrated, eg, Nebraska Sandhill pond, nb in Figure 1. The waters of Nakuru, a fishless soda lake in Kenya, contain 45,000 ppm TDS, making it difficult to isolate the effect of its high pH. Still, in some dilute lakes, especially those relatively high in sodium, late summer fish kills happen occasionally. This is true for some volcanic lakes near Flagstaff, Arizona, when bluegreen photosynthesis (especially due to *Aphanizomenon*) raises the pH, and a trout die-off follows. From the data presented by Beadle (1974) for tropical Africa it appears that no fish survive a consistent pH of 10.3, although several lakes with pH >9 support 25 to 50 species.

The relationships shown in Figure 1 illustrate some complexities in lake classification. It might be an excellent scheme in some instances to group lakes on the basis of MEI; the index could serve nicely to make rough categories, and the same might be said about similar indices, for example, the one proposed by Schindler (1971). Regionally such classifications might be useful, but generalizations would break down in different climatic-geographic settings. And factors such as the extremes in salinity, hydrogen-ion concentrations, free CO_2, and in some instances ionic proportions or inhibitory ions, assume importance and are worthy of inclusion in classification schemes.

ZAFAR'S LAKE TAXONOMY

Zafar (1959) published a paper entitled "Taxonomy of Lakes" in which he proposed a terse manner of setting down the fundamental characteristics of a body of water. It was not a simple binomial system; rather there were four main components with subdivisions. The first described the trophic situation as oligotrophic, eutrophic, or heterotrophic with a Greek-letter prefix for subdivisions. In this part the levels of P, N, Ca, and humus were taken into account, and the "basic ratio" was also incorporated. This is $\frac{Na + K}{Ca + Mg}$ and is assumed to be <1.2 in eutrophic waters and >2 in oligotrophic lakes. The validity of this plan breaks down when we reflect on some of the world's highest productivities--in soda lakes where the so-called basic ratio is high.

The major tributaries of the Colorado River in the Grand Canyon fall into two main groups: those with a high proportion of monovalent to bivalent ions, and those with a low ratio (Kubly and Cole unpubl. ms. 1976). But there are two distinct types in the former group--the saline sodium chloride waters such as Blue Spring and Pumpkin Spring, and the dilute sodium bicarbonate waters represented by Diamond Creek and Travertine Falls Creek. A number quantifying the "basic ratio" is not precisely descriptive of the habitat without further information.

Next in Zafar's taxonomy is a Greek letter to designate one of six categories of basin shape. He settled on the volume development index (DV) as the best way of describing lake morphology. Thus, *alpha* represents those basins with a D_V <0.4 and *lambda* refers to those with D_V >2. There is some haziness here, and without further description one cannot be certain what the concavity actually resembles. For example, a Petri dish and a 1,000-ml graduated cylinder have identical D_V indices; two quite divergent lakes, shaped like those items of laboratory glassware would be scored alike, despite their contrasting morphologic features. Both lakes are designated *lambda*.

The third part of Zafar's taxonomy placed the lake geographically according to latitude and altitude. Nordlie's (1956) Florida lakes, mentioned earlier, are the *subtropico-absolutae* type because they lie between latitudes 20°-40° at an altitude <914m above sea level.

The ultimate part of the nomenclature is based on the predominant phytoplankton taxon. Husain Sagar Lake in South India was given as an example of the completed taxonomy: *gamma-eutrophic Beta-tropico-absolutae Bacillariae*. We know from this that diatoms are prevalent in the open water of the lake. This is vague information unless the regional limnology is well known and there is some significance to abundant diatoms. A dominance of *Cyclotella* for example means something different from an *Asterionella* bloom. Perhaps it should be assumed that the diatoms in Husain Sagar are represented by

Asterionella and Fragilaria rather than Cyclotella because of the preceding eutrophic designation.

The string of symbols and words that describe Husain Sagar tells us that it is a lake relatively rich in N, P, and calcium, low in humus, lying below 914 m elevation, and more than 20° from the equator. The concavity it occupies could be: uniformly flat-bottomed with the exception of an anomalous deep hole somewhere; a small, originally funnel-shaped depression, its side slumped in and now convex toward the water; or a basin characterized by extensive broad shoal areas surrounding central deep water. Samples from the open water contain many diatoms, but we do not know what indicator species, if any, are present.

CONCLUSIONS

Beadle (1974:307) remarked on "...the common illusion that a phenomenon with a label attached is thereby explained." Lake typology as a goal has not been without value, of course; out of it have emerged patterns that advanced limnology and ecology in general. Continuing the search for pigeonholes into which lakes can be fitted naturally on regional bases can lead to understanding of the local aquatic habitats and their potentials. There is, however, little chance that a couple of adjectives can explain the complexities and dynamics of a lentic habitat.

LITERATURE CITED

Armitage, K.B. 1958. Lagos volcánicos de El Salvador. Commun. Inst. Trop. Invest. Client. 7:39-48.

Bayly, I.A.E., and W.D. Williams. 1973. Inland Waters and their Ecology. Longman Australia Pty. Ltd., Camberwell. 316 pp.

Beadle, L.C. 1974. The Inland Waters of Tropical Africa: An Introduction to Tropical Limnology. Longman Gp. Ltd., London. 365 pp.

Cole, G.A., and G.L. Batchelder. 1969. Dynamics of an Arizona travertine-forming stream. J. Arizona Acad. Sci. 5:271-283.

Cole, G.A., and W.T. Barry. 1973. Montezuma Well, Arizona, as a habitat. J. Arizona Acad. Sci. 8:7-13.

Harvey, H.H. 1975. Fish populations in a large group of acid-stressed lakes. Verh. Internat. Verein. Limnol. 19:2406-2417.

Hutchinson, G.E. 1957. A Treatise on Limnology: Vol. I. Geography, Physics, and Chemistry. John Wiley & Sons, Inc., New York. 1,015 pp.

Hutchinson, G.E., and H. Löffler. 1956. The thermal classification of lakes. Proc. Nat. Acad. Sci. 42:84-86.

Järnefelt, H. 1956. Zur Limnologie einiger Gewässer Finnlands. XVI Mit besonderer Berücksichtigung des Planktons. Ann. Zool. Soc. Bot. Fennicae (Varano). 17(1):1-201.

Kemp, P.H. 1971. Chemistry of natural waters--VI. Classification of waters. Water Res. 5:945-956.

La Perriere, J.D., L.A. Casper, and F.C. Payne. 1975. Difficulties in assigning a trophic state to a deep subarctic lake. Verh. Internat. Verein. Limnol. 19:480-486.

Likens, G.E. and F.H. Borman. 1974. Acid rain: a serious regional problem. Science 188:1176-1179.

Lundquist, G. 1927. Bodenablagerungen und Entwicklungstypen der Seen. Die Binnengewässer II. Stuttgart. 124 pp.

Malueg, K.W., J.R. Tilstra, D.W. Schults, and C.F. Powers. 1972. Limnological observations on an ultra-oligotrophic lake in Oregon, U.S.A. Verh. Internat. Verein. Limnol. 18:292-302.

Margalev, R. 1975. Typology of reservoirs. Verh. Internat. Verein. Limnol. 19:1841-1848.

Moyle, J.B. 1945. Some chemical factors influencing the distribution of aquatic plants in Minnesota. Amer. Midl. Nat. 34:402-420.

Moyle, J.B. 1956. Relationships between the chemistry of Minnesota surface waters and wildlife management. J. Wildl. Mgt. 20:303-320.

Naumann, E. 1917. Undersökningar över fytoplankton och under den pelagiska regionen försiggående guttje-och dybildningar inom vissa syd- och mellansvenska urbergsvatten. Kungl. Svenska Vetenskapsakademiens Handlingar 56(6): 1-165.

Naumann, E. 1919. Några synpunkter angående limnoplanktons ökologi med sarskild hansyn till fytoplankton. Sv. Bot. Tidskr. 13:129-163.

Naumann, E. 1932. Gründzuge der regionalen Limnologie. Die Binnengewässer XI. Stuttgart. 176 pp.

Nordlie, F.G. 1976. Plankton communities of three central Florida lakes. Hydrobiologia 48:65-78.

Rawson, D.S. 1952. Mean depth and the fish production of large lakes. Ecology 33:513-521.

Rodhe, W. 1969. Crystallization of eutrophication concepts in northern Europe. pp. 50-64. In Eutrophication: Causes, Consequences, Correctives, Nat. Acad. Sci., Washington.

Rodhe, W. 1975. The SIL founders and our fundament. Verh. Internat. Verein. Limnol. 19:16-25.

Ryder, R.A. 1965. A method for estimating the potential fish production of north-temperate lakes. Trans. Amer. Fish. Soc. 94:214-218.

Ryder, R.A., S.R. Kerr, K.H. Loftus, and H.A. Regier. 1974. The morphoedaphic index, a fish yield estimator--review and evaluation. J. Fish. Res. Bd. Canada 31:663-688.

Schindler, D.W. 1971. A hypothesis to explain differences and similarities among lakes in the Experimental Lakes Area, northwestern Ontario. J. Fish. Res. Bd. Canada 28:295-301.

Teiling, E. 1916. En Kaledonisk fytoplanktonformation. Svensk. Bot. Tidskr. 10:506-519.

Thienemann, A. 1909. Vorläufige Mitteilung über Probleme Ziele der biologischen Erforschung der neun westfälischen Talsperren. Ber. Versamml. Bot. Zool. Ver. Rheinl.-Westf., Jg 1909:101-108.

Thienemann, A. 1915. Physikalische und chemische Untersuchungen in den Maaren der Eifel. II. Verh. Naturhist. Ver. Preuss. Rheinlande u. Westfalens 71:273-389.

Thienemann, A. 1925. Die Binnengewässer Mitteleuropas: Eine Limnologische Einführung. Die Binnengewässer I. Stuttgart. 255 pp.

Vollenweider, R.A. 1968. Scientific Fundamentals of the Eutrophication of Lakes and Flowing Waters, with Particular Reference to Nitrogen and Phosphorus as Factors in Eutrophication. OECD Rep. DAS/CSI/ 68.27 Paris. 192 pp.

Walker, K.F., and G.E. Likens. 1975. Meromixis and a reconsidered typology of lake circulation patterns. Verh. Internat. Verein. Limnol. 19:442-458.

Weber, C.A. 1907. Aufblau and Vegetation der Moore Norddeutschlands. Bot. Jahrb. 40 Beibl. 90:19-34.

Wetzel, R.G. 1966. Variations in productivity of Goose and hypereutrophic Sylvan lakes, Indiana. Invest. Indiana Lakes Streams 7:147-184.

Zafar, A.R. 1959. Taxonomy of lakes. Hydrobiologia 13:287-299.

CLASSIFICATION OF COASTAL ENVIRONMENTS

John Clark
Senior Associate
The Conservation Foundation, 1717
Massachusetts Avenue, N.W.,
Washington, D.C.

Abstract: Classification and inventory data need to be collected and analyzed before a strategy is set for maintaining and/or developing a particular class of ecosystem or type of habitat. Ecologically comprehensive classification of coastal and marine habitat requires complete understanding of the physical and biological processes involved. The terrestrial coast is regionalized into natural ecosystem types: watershed, floodplain, wetland, shoreland, dune, beachfront, and importantly, all ecotones between such areas and the aquatic milieu. Coastal waters are subcategorized into estuarine, bay, embayment, lagoon, nearshore and oceanic regimes, including pertinent ecotones.

Nine general areas are described for comprehensive inventory data collection: topography, soil, vegetation, geology, hazard areas (high erosion, flood potential, storm impact areas, etc.), specific critical habitat, vital area elements, wildlife and other valuable resources. Inventory data used with a regionalized ecosystems approach provide preliminary information necessary for resource managers to characterize and identify natural habitats.

A thorough job of planning is the precursor to coastal zone resource management whether at local, State, or Federal levels. The comprehensive planning and the specification of environmental controls that is required for effective ecosystem management must be done with full knowledge of the natural system and its elements.

SURVEY OF NATURAL SYSTEMS AND RESOURCES

In planning programs, the services of ecological specialists usually will be required to survey the soils, waters, and the biota of both the shoreland and the coastal basin subsystems. Such a survey is necessary to establish the carrying capacity limits of the natural system and to reveal points of vulnerability of the ecosystem to adverse impacts of various kinds. From the survey the area can be subdivided into zones of different carrying capacity (Figure 1). This information may also be used as the basis for selection of environmental standards to be used to define permitted uses, to identify ecologically vital areas, and to establish a general strategy for development. It will also suggest the designation of exempt ecologically vital areas or performance standards (for example, dredging limitations) needed to protect the ecosystem and to optimize carrying capacity.

THE COASTAL ZONE

The coastal zone is quite logically separated into two major subsystems--Shorelands and Coastal Waters. It takes both to make up a complete coastal ecosystem. The major connection is provided by water flow.

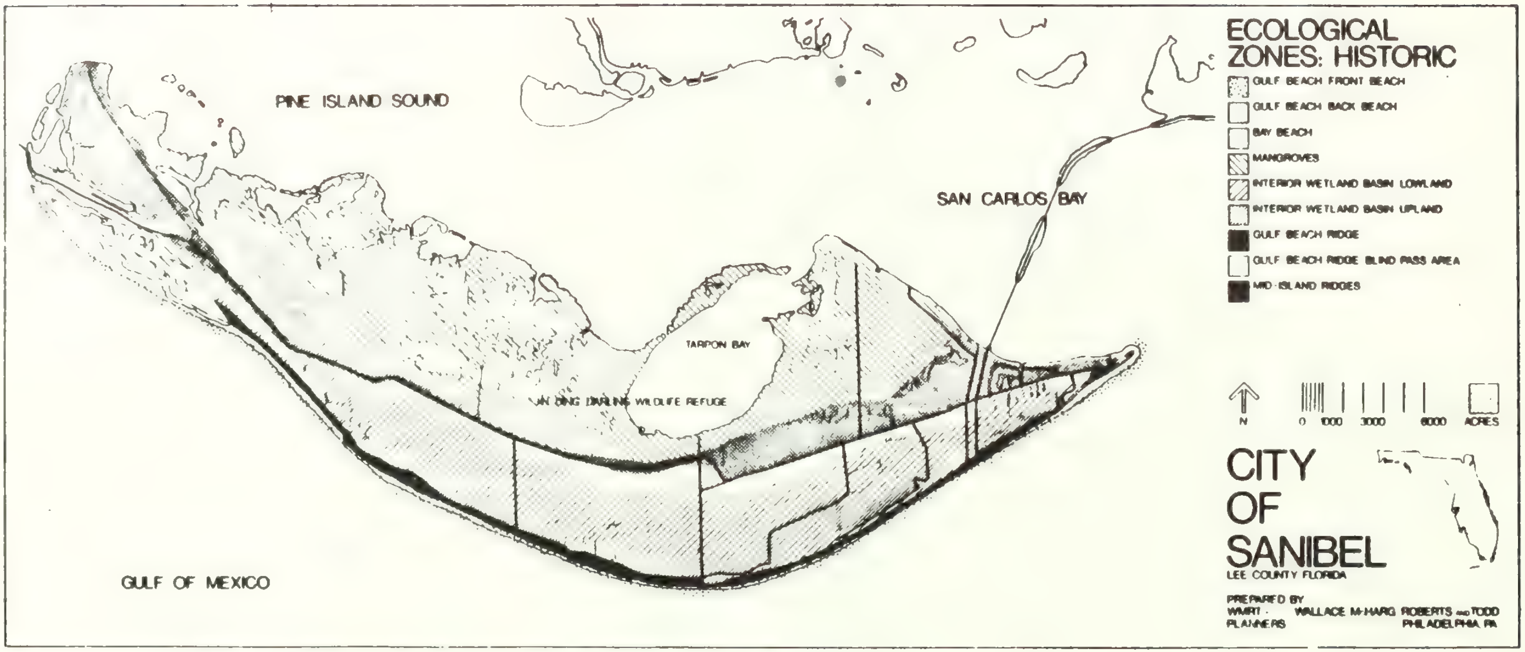


Figure 1. Comprehensive land use plan: City of Sanibel, Lee County, Florida (Wallace et al. 1975).

The designation of the coastal zone in various States generally begins with a definition of the natural system and ends with boundaries set for administrative convenience. Typically, the extent of "coastal waters" is defined first and then a strip of shoreland is added to embrace the interlocking land and sea elements of coastal zone management. The Federal government has developed a process for such designation that local governments must follow if they (and their State) are participating in the Federal coastal zone management program. The Coastal Zone Management Act identifies the parameters which a State must use in identifying its boundaries by defining the coastal zone as the "coastal waters (including the lands therein and thereunder) and the adjacent shorelands (including the waters therein and thereunder), strongly influenced by each other and in proximity to the shorelands of the several coastal States, and includes transitional and intertidal areas, salt marshes, wetlands, and beaches." (Coastal Zone Management Act 1972, Public Law 92-583).

The properties of the waters that characterize the watersheds and water basins of coastal ecosystems provide the best basis for the administrative definition. For practical purposes of defining coastal waters, we recommend that a value of 0.5 ppt salinity be used as the least "measurable quantity or percentage of seawater" because it is the lowest value that consistently could be ascribed an important ecologic meaning in most cases and because it can be detected by simple field equipment (this amount of salt is just above the taste threshold). In view of the larger problems of defining boundaries in this area of oscillating salinity, it would seem unreasonable to require the high level of accuracy that is available only with sophisticated laboratory equipment.

The most satisfactory method for fixing the inner boundary of the zone is a biotic survey. The fixed (immobile) biotic community of tidal rivers and similar areas varies with the salt content of the water. The proportion of various species gradually shifts from the sea toward the head of the estuary. At the point where salt content falls below an average of about 0.5 ppt there is usually a sudden and dramatic change which signals the ecological boundary between the estuary and fresh waters--that ecological reference point above which at most times there is no longer a "measurable amount" of salt. This boundary would be useful in setting the inner boundary of coastal waters because it integrates the effects of the whole range of variation in salinity on a long term basis. Specifically, the boundary should be drawn at the point where the fixed biotic community shifts to over 50 percent endemic estuarine forms of life in any category (marsh grasses, molluscs, gastropods, nematodes, etc.). It is clear that the identifying biota should be those with extended life cycles (1 year or more) and those that are nonmobile. A more expanded special (perhaps regional) management area may be needed to protect the freshwater spawning areas of anadromous tidal fishes such as striped bass (_Roccus saxatilis_) salmon, and shad.

SURVEY OF NATURAL SYSTEMS AND RESOURCES

The principal items of natural systems interest are vegetation, soils, hydrology (water systems), geology, and topography. Survey of each of these should be included in the planning program. Inventories also may include identification and evaluation of such nonecologic but natural factors as scenic and recreational resources and natural hazard areas. The need for such surveys and the basic methods are known to most professional planners and are not unique to coastal zone environments.

The major natural systems elements of interest are briefly described below:

1. Topography--sometimes called "slope, geography, relief of physiography." A survey of the surface landform (hills, mountains, ridges, valleys) including a delineation of the surface relief by contour mapping (Figure 2).

2. Hydrology--sometimes called "water or drainage systems." A survey of the municipality's water systems (streams, rivers, ponds, lakes, swamps, bogs, oceans, and tidal marshes) including underground water supplies. Soils or subsurface geology may also be included. Water is a most important factor in the natural systems and resource survey in all communities since it is a necessity of life and can be a severe limiting factor to increased residential or industrial growth. In coastal communities it is usually the most important because of the critical role of water in governing ecosystems and limiting carrying capacity.

3. Soils--sometimes called "surficial geology." A survey of the soil properties in terms of: intrinsic fertility for agriculture, ability to support structure, depth to water table, ability to absorb water, both natural and effluent from septic systems, depth to bedrock, ability to support plant life other than crops, and in coastal communities a basic land suitability factor and a major control factor on water systems.

4. Vegetation--a survey of the plant communities of the municipality in terms of their usefulness for soils and water retention and aesthetics, and for basic information on wildife populations. In coastal communities it provides a basic indicator of vital areas, critical areas, and provides the framework for identification of separate elements of the ecosystem.

5. Geology--sometimes called "sub-surface" or "bedrock geology" to differentiate from "surficial geology." A survey of the underlying rocks and parent materials of soils. This category can also include consideration of underground water supply in terms of wells, aquifers, and aquifer recharge areas.

6. Hazard areas--a survey of all natural hazards such as areas subject to earthquakes, mud and rock slides, flooding, high rates of erosion, and impacts of storm waves.

7. Wildlife and other valuable resources--a usual "catchall" survey that may include historic or cultural sites, areas of scenic interest, mineral deposits, or areas of national, State, or regional significance. In some cases, where only one or two of these factors exist, they can be listed as separate categories. Wildlife often does not receive a high level of recognition in local planning. In the coastal zone this survey should include fish and shellfish resources, along with feeding, breeding, and wintering areas, and other places of special significance such as vital habitat, productivity, or structural areas.

8. Areas of concern--a concept developed in the last decade. The areas of critical concern concept has developed concurrently in various Federal and State land planning studies over the past several years. They are called "areas of particular concern" in the Federal coastal zone program. Although it has been articulated in a variety of ways and has come to have a variety of implications, the basic concept remains the same--there are certain critical environmental areas which, because of their natural attributes, require special management attention. Such critical areas are identified as those where uncontrolled development might lead to significant adverse environmental impacts.

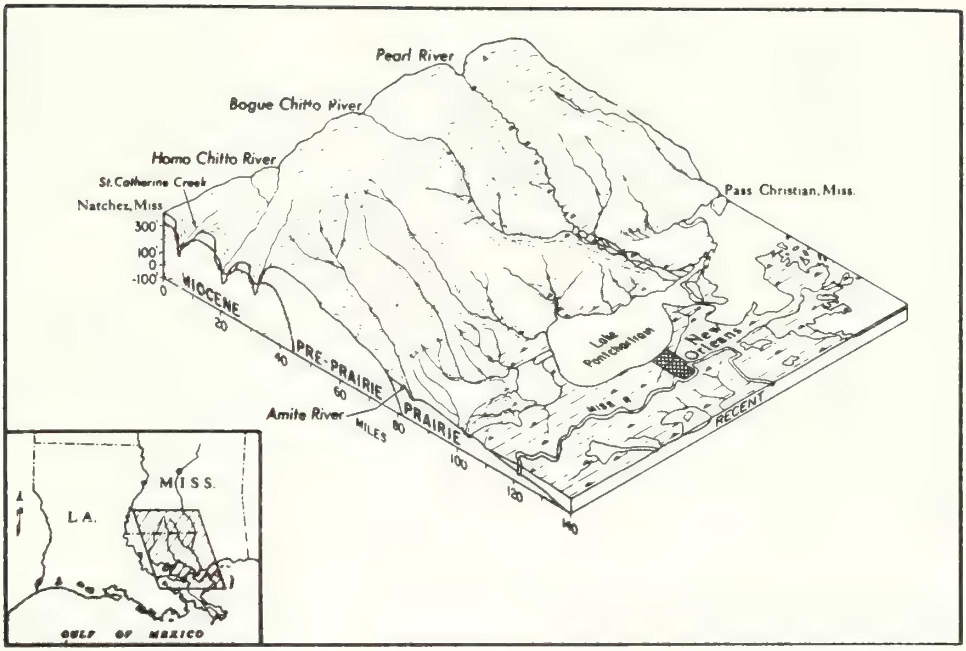


Figure 2. Geologic setting of the New Orleans area. In contrast to the wetlands in the immediate vicinity of the city, Pleistocene terrace surfaces on the north shore of Lake Pontchartrain are well above sea level, naturally drained, and in general ideally suited for urban development (Gagliano 1973).

Therefore, some restriction on use and some control on activity is required. Often these attributes are environmental, including natural hazards, although sometimes they include cultural values (related to activities of mankind).

9. Vital areas--a new classification of special relevance to the coastal zone. Vital areas are defined as those elements of such importance to the functioning of the coastal ecosystem that they must be preserved as intact units by disallowing uses that would alter them significantly. The vital areas are related to the broader system of resource capability designation that classified broad areas that are ecologically sensitive as critical areas in the sense that every vital area is part of a critical area.

VITAL AREA TYPES

One can discriminate three types of vital areas. Vital habitat areas are those that chiefly provide general living space for particular species; coral reefs, for example. Vital productivity areas are those that chiefly supply nutrient to the system, for example, a high marsh. Vital structural areas are those that physically protect the ecosystem through their structure, for example, sand dunes. Some areas serve a single vital function, while others serve two or perhaps all three functions.

VITAL HABITAT AREAS

The following classes of vital areas provide high value for habitat in coastal ecosystems for a variety of animal species: coral reefs, kelp beds, shellfish beds, grass beds, lower wetlands, breeding areas, nursery areas, wintering areas, and migration pathways.

Vital habitat areas are places where the species concentrate in high abundance and without which their welfare would be significantly endangered. Many species are particularly vulnerable to damage when concentrated in their special feeding, breeding, nursery, or wintering areas or on migration pathways--these should all be located and mapped for protection as vital areas. Their identification and description is usually a job for a zoological expert.

VITAL PRODUCTIVITY AREAS

The following classes of vital areas provide high values in the production and storage of primary productivity in coastal ecosystems (coral reefs, lower wetlands, upper wetlands, tide flats, grass beds, kelp beds).

VITAL STRUCTURAL AREAS

The following classes of vital areas provide high value for providing structural integrity to coastal ecosystems (sand dunes, coral reefs and wetlands).

These vital areas serve to protect the valuable landward estuarine and shoreland systems from storm damage and erosion.

VEGETATION AND HYDROLOGY SURVEY

In planning for a coastal zone environmental management program one should conduct an exhaustive survey of the flora, including vegetation in drainageway corridors and in the floodplains, wetlands, tidelands, and bottomland. Plant and plant community types are the best indicators of the natural characteristics that identify the especially valuable ecologic units or vital areas such as coastal marshes and mangrove swamps, freshwater wetlands, and submerged grassbeds.

Hydrologic factors control the abundance and diversity of plantlife in coastal areas and therefore determine the natural patterns of vegetation. Topography, water quality, and soil condition are closely associated factors. Many aspects of coastal land use management relate to the patterns of vegetation (Figure 3). Patterns of vegetation are the key to identification of land and water capability types and therefore a basis of land use classification. In addition, certain vital areas are to be preserved because of the ecologic value of their vegetation.

The survey of vegetation, of shorelands and coastal water basins, required for planning purposes can be facilitated by following the natural zonation of vegetation. At the basin margin, zonation is governed by the joint influence of fresh water and saltwater-tides are particularly important (various designations of tidal-and storm-water levels are explained in Figure 4). The following is a convenient classification of natural vegetation in coastal zones (keyed to Figure 5):

Shorelands

1. Upland vegetation

2. Floodplain vegetation

Coastal Waters Province

3. Upper wetland vegetation

4. Lower wetland vegetation

5. Submerged vegetation

6. Barrier island vegetation complex

Each of the above six classes may be further divided into categories representing recognizable vegetative subzones. For example mangrove wetlands may contain separate red mangrove (*Rhizophora* sp.) and black mangrove (*Avicennia* sp.) Subzones.

In management, knowledge of vegetation may be essential because the presence of vegetative indicators on a parcel of land would trigger a special administrative review for a development proposal on the presumption that it could significantly alter a wetlands area (Table 1). But it is also important to recognize that the vegetation is in itself valuable for the many functions described previously and requires protection for these values as well as serving as an indicator.

COASTAL WATERS

The coastal waters subsystem can be conveniently categorized in three identifiable and functionally distinct regimes: the Estuarine Regime, the Nearshore Regime, and the Oceanic regime.

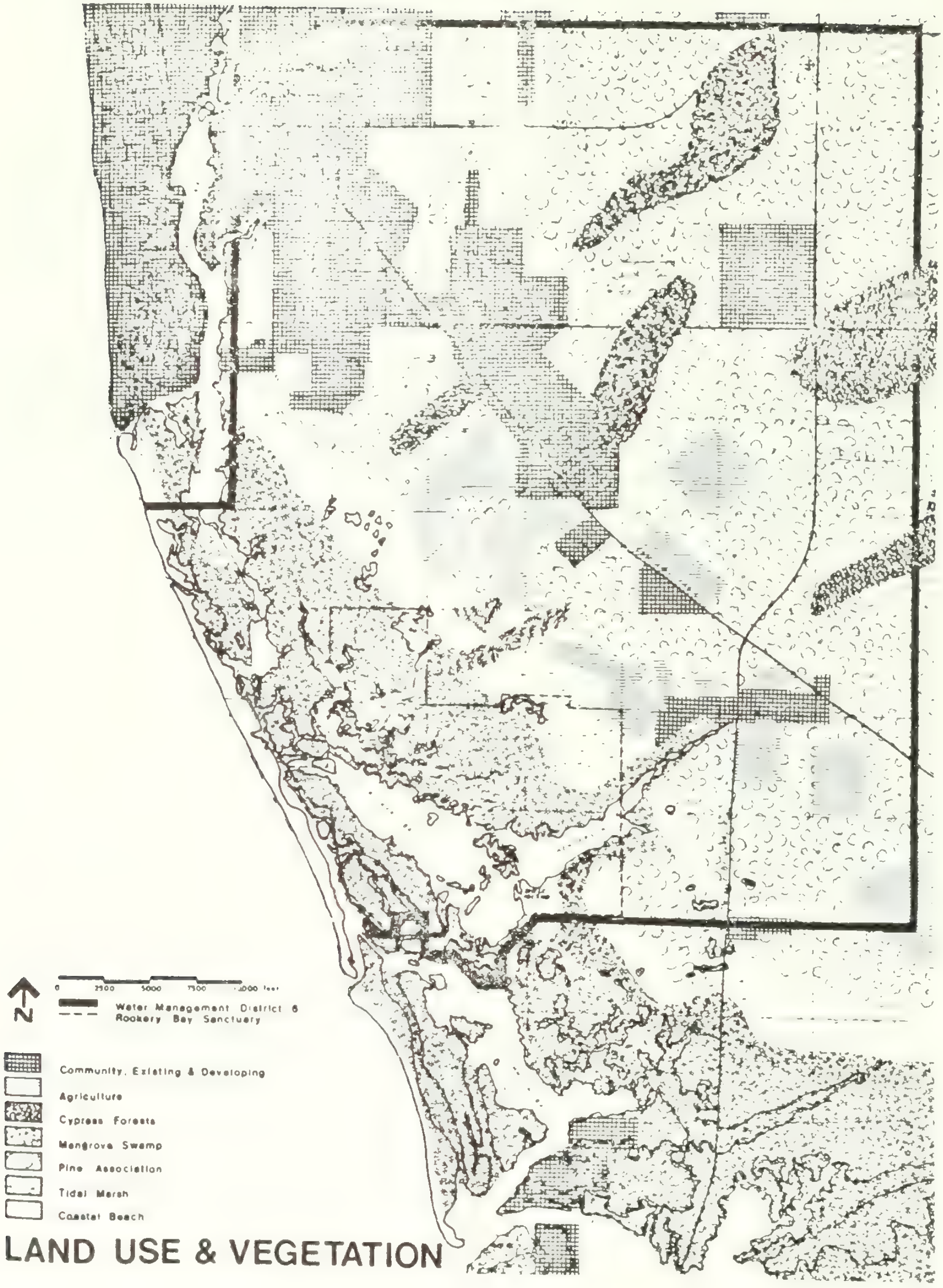
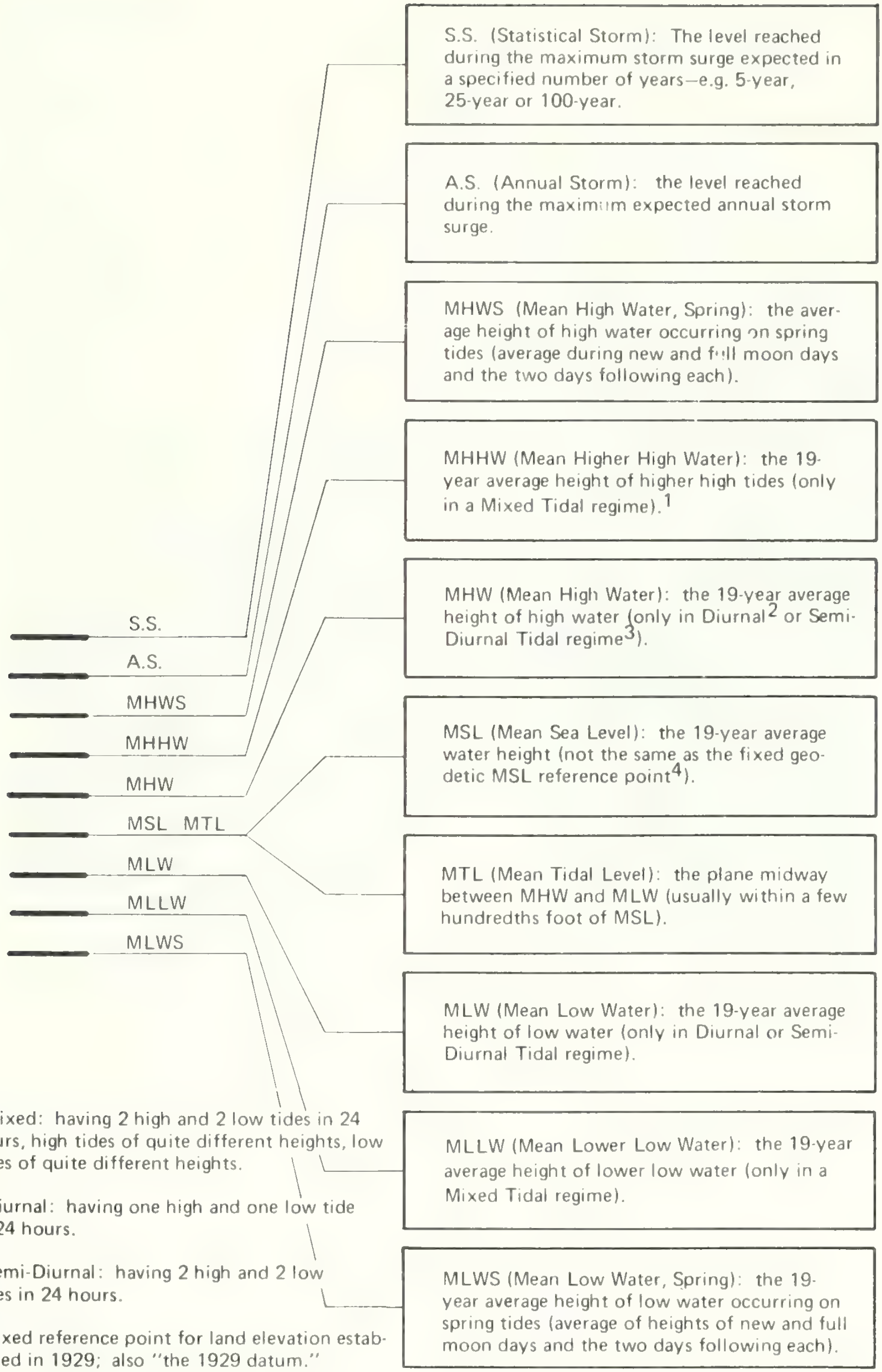


Figure 3. Water Management District 6 with generalized patterns of vegetative cover and land use, Collier County, Florida (Veri et al. 1973).



S.S. (Statistical Storm): The level reached during the maximum storm surge expected in a specified number of years—e.g. 5-year, 25-year or 100-year.

A.S. (Annual Storm): the level reached during the maximum expected annual storm surge.

MHWS (Mean High Water, Spring): the average height of high water occurring on spring tides (average during new and full moon days and the two days following each).

MHHW (Mean Higher High Water): the 19-year average height of higher high tides (only in a Mixed Tidal regime).[1]

MHW (Mean High Water): the 19-year average height of high water (only in Diurnal[2] or Semi-Diurnal Tidal regime[3]).

MSL (Mean Sea Level): the 19-year average water height (not the same as the fixed geodetic MSL reference point[4]).

MTL (Mean Tidal Level): the plane midway between MHW and MLW (usually within a few hundredths foot of MSL).

MLW (Mean Low Water): the 19-year average height of low water (only in Diurnal or Semi-Diurnal Tidal regime).

MLLW (Mean Lower Low Water): the 19-year average height of lower low water (only in a Mixed Tidal regime).

MLWS (Mean Low Water, Spring): the 19-year average height of low water occurring on spring tides (average of heights of new and full moon days and the two days following each).

[1] Mixed: having 2 high and 2 low tides in 24 hours, high tides of quite different heights, low tides of quite different heights.

[2] Diurnal: having one high and one low tide in 24 hours.

[3] Semi-Diurnal: having 2 high and 2 low tides in 24 hours.

[4] Fixed reference point for land elevation established in 1929; also "the 1929 datum."

Figure 4. Reference tidal heights for coastal waters.

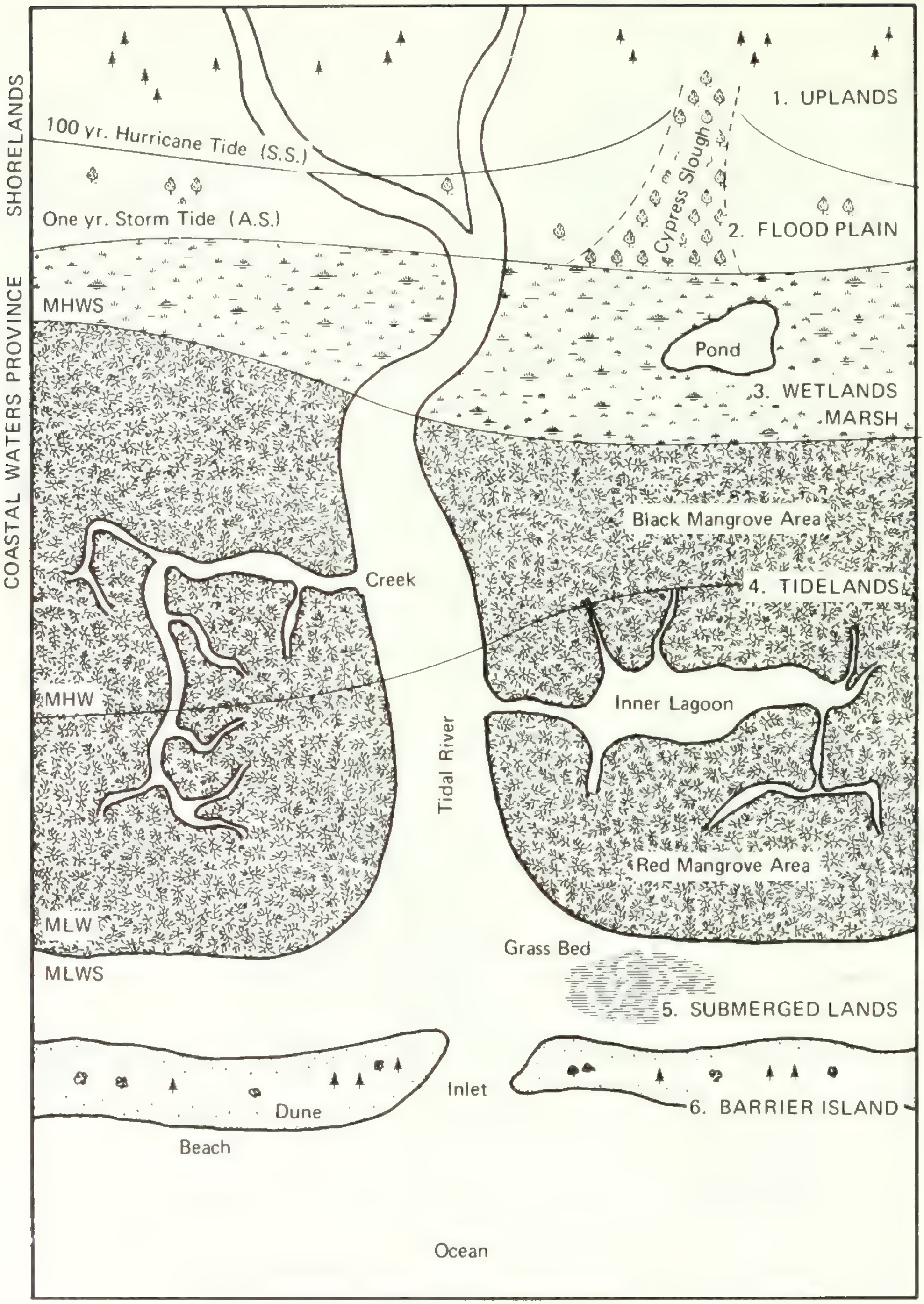


Figure 5. Vegetative zonation of a hypothetical mangrove coastal area in Southwest Florida. Arrows indicate the general flow pattern (not to scale).

Table 1. Vegetative Indicators of Saltwater and Freshwater Wetland areas in Southern Florida (Clark 1974)

Common Name	Scientific Name
Marsh fleabane	*Pluchea foetida*
Sawgrass	*Cladium jamaicensus*
Arrowhead	*Sagittaria* sp
Pickerel weed	*Pontederia lanceolata*
Cattail	*Typha augustifolia*
Leather fern	*Acrostichum daneafoliom*
Bald cypress	*Taxodium distichum*
Pond cypress	*Taxodium ascendens*
Sweet bay	*Magnolia virginiana*
Buttonbush	*Cephalanthus occidentalis*
Pond apple	*Annona glabra*
Popash	*Fraxinus caroliniana*
Willow	*Salix* sp
Glasswort	*Salicornia* sp
Saltwort	*Batis maritima*
Needlerush (black rush)	*Juncus roemerianus*
Seashore saltgrass	*Distichlis spicata*
Salt cordgrasses	*Spartina* sp
Wild Allamander	*Urechites lutea*
Rubber vine	*Rhabdadenia biflora*
Black mangrove	*Avicennia nitida*
Red mangrove	*Rhizophora mangle*
White mangrove	*Laguncularia racemosa*
Button wood	*Conocarpus erecta*

ESTUARINE WATER REGIME

The term estuary has a variety of definitions, the best of which is: An estuary is an enclosed coastal water body with a free connection to the sea and a measurable quantity of salt in its waters (Clark 1977). "Measurable" can be interpreted as greater than 0.5 ppt salinity. This definition is used in preference to one which includes only those enclosed water bodies that received a "significant" freshwater input. The chosen definition includes all enclosed or "protected" coastal waters and avoids the problem of dealing with "lagoons" separately from estuaries because their rate of inflow from the land is low. A lagoon can be considered as one of the many different types of estuary wherever it is necessary to make a distinction for management purposes (e.g., because of poor flushing).

Where it is important to distinguish between estuarine and open areas for planning or management purposes the following "rule of thumb" based upon the degree of confinement is used: a confined coastal waterbody, or estuary, is one that has a shoreline length in excess of three times the width of its outlet to the sea.

The estuarine system includes the water basin (or basins) and the marginal areas found around the edge of the basin that are seasonally flooded by tides or storms. Water basins may be embayments, bays, sounds, fiords, lagoons, salt ponds, or tidal rivers. The marginal area includes the tideflats and mudflats, the lower wetlands, tidal salt marshes and mangroves, and the upper wetlands (high marsh flooded by spring tides) back to the limit of annual flooding (the 1 year floodmark) where the floodplain begins and the shorelands start.

Coastal water basins occur in a nearly limitless variety of shapes and sizes. The four water basin types discussed below will include most cases. The well-enclosed water bodies are normally distinct, readily recognized, and easily treated in management; however, sectioning the ocean into workable, distinguishable units is quite difficult.

Estuaries are of particular management interest because of their exceptionally high carrying capacity and their distressing vulnerability--they are classified for management as areas of critical environmental concern. The four major basin types are:

(1) Tidal river. A tidal river is the lower reach of a river that enters the sea, often via an estuarine basin. The coastal segment of the river--that of primary management interest--extends as far upstream as there is significant salt content in the water (0.5 ppt). The boundary area is the salt front. The freshwater part is normally excluded, even if it is tidally influenced, or relegated to a secondary management district. Tidal rivers are normally well-flushed by the combined, but opposing, actions of freshwater outflow and tide.

(2) Bay. The larger, semienclosed, coastal waters are bays (here including sounds, to simplify classification). Many water bodies which are really embayments or lagoons are misnamed as "bays." Such water basins should be classified in the management system proposed here in accordance with their natural characteristics, not their present colloquial designations. Bays are typically quite open to the sea, receive strong tidal flow, are well flushed through tidal exchange, and often receive considerable additional circulation-driving power from freshwater inflow.

(3) Embayment. Embayments are confined coastal water bodies with narrow restricted inlets and with significant freshwater inflow. They usually have narrower inlets than bays and are generally shallower and smaller than bays. Embayments usually have relatively low tidal amplitude and water circulation may be sluggish, resulting in a poor rate of flushing, unless freshwater input is particularly high. In these, and other respects, embayments are intermediate between bays and lagoons.

(4) Lagoon. Lagoons are confined coastal water bodies with restricted inlets to the sea and with little freshwater inflow. They tend to have sluggish water movement and to be especially vulnerable to pollution, thus their carrying capacity often has been severely reduced by human development around their shores. The aquatic communities of lagoons may be quite different from those of other basins because of higher and relatively constant salinity, somewhat higher and more constant pH, the dominant but variable role of wind-driven circulation, the accumulation of organic sediments on their bottoms, and other factors.

NEARSHORE AND OCEANIC REGIMES

The nearshore regime includes all marine waters, seaward of the estuarine boundary and shoreward of the territorial sea (nominally 3 miles [4.8 km] distance from the shore). The terms "inshore" or "inshore waters" have such varied meanings they are of little use in classification.

The oceanic regime includes all water seaward of the boundary of the territorial sea.

"Exposed coasts" are ocean shorefronts characterized by either solid rock formations or by heavy deposits of sand. The great capacity of the dunes and beach berms for storage of sand makes them the chief stabilizers of the sandy ocean beachfront. Water movement is usually strong, and the mixing, dilution, and dispersal of wastes is rapid along exposed coasts.

"Sheltered coasts" occur in certain places along the ocean shorefront where the ocean bottom slopes gradually to the shore and where offshores sandbars thrown up by the force of waves provide a barrier or where coral reefs have built up in a barrier formation seaward of the shorefront. These sand or coral barriers provide a sheltered area inside the bar or reef where the ecosystem is in many ways characteristic of estuarine waters--marine grasses grow, shellfish prosper, and nursery areas for young fishes are found. In addition, there are "low-energy" coasts (such as in the northwest Florida shore), where wave action is so reduced that, even without a pronounced offshore bar, the coast is sheltered in character, the water is flushed more slowly, and semiestuarine characteristics prevail.

MARGINAL AREAS

At the margin of each estuarine and nearshore coastal water basin is a transitional area that is classified as part of the coastal basin, where it is flooded daily by the tides or only yearly by a severe storm. This area is part of the coastal waters subsystem. It may be barren sand or rock or vegetated by coastal wetland plants. Most often, in protected estuarine areas it is vegetated, except the lowest elevations, which grade into tidal flats. But vegetation may be absent from most of the area of the exposed ocean coast, at least below the high water mark.

The seaward boundary of the marginal area is the lowest elevation expected to be exposed at ebbtide during the course of a year, and is thus below mean low water. This boundary may have little administrative significance because the coastal water basin is normally in the public domain seaward from the mean low water mark (but from the mean high water mark in some States).

The landward boundary of the marginal area of the coastal basin is the highest elevation expected to be flooded by coastal waters during the course of a year. This boundary is extremely important administratively, because it marks the upper boundary of the wetlands.

A simpler and more reliable approach is through the use of indicator plants. A biotic survey can determine the inner extent of saltwater influence--the line above which there is no "measurable" effect of saltwater inundation or penetration (Smith and Wood 1973).

There are many difficulties in locating the upper boundary by water level surveys. For example, the sea level is rising gradually along much of the U.S. coast--more than a foot (30.5 cm) per century in some areas. Often more troubling is the annual rhythm of rise and fall of sea level, whereby the sea level may be much higher in autumn, for example, than in spring. In addition there are daily and monthly cycles and irregularities caused by wind variation, freshwater runoff, and other factors. There are also significant differences between the tidal responses of estuaries and the sea.

SHORELANDS

While the shorelands are ecologically complex and have high resource values, here they are discussed only in relation to their interaction with coastal water systems and their influence on the carrying capacity of coastal ecosystems. Because this influence operates mostly through discharge of runoff water, coastal water concerns are specifically directed toward coastal watersheds, lands that drain directly into coastal waters (of more than 0.5 ppt salinity). These lands are defined as, and referred to as, the shorelands. Lands that drain wholly into freshwaters (less than 0.5 ppt), tributary to tidal waters, are not shorelands for coastal zone management purposes and would be excluded from the primary management area.

In the suggested context, there are three elements of specific importance to be identified, classified, and surveyed: (1) all subwatersheds of the coastal watershed; (2) the complete water system of each subwatershed, including standing waters (ponds, lakes), natural detention areas (bogs, marshes), drainage courses (streams, swales), and (3) all coastal floodplains (variations such as 100-year, 25-year, and 10-year may be needed for various management purposes) including high storm-hazard and erosion-hazard areas and vital structural areas such as sand dunes. An important part of the survey and identification process for each of the three is to locate and evaluate all vital areas (habitat, structural, and productivity).

The survey elements recommended above emphasize only factors that can affect coastal ecosystems. Nevertheless, it must be recognized that many coastal programs will need to expand the survey program to include areas of noncoastal water interest. This broader survey is typical of advanced local land use planning studies that include breeding areas, endangered species habitats, geological faults, scenic vistas, and so forth.

COASTAL WATERSHEDS

Coastal land and water use management planners have to recognize that water provides the essential linkage of land and sea elements of the coastal ecosystem. Thus, water management in its many aspects is a primary consideration of the shorelands. We have defined "shorelands" to include all the terrain of the coastal watershed. Shorelands thus extend down to the upper boundary of the coastal water basin, which conincides with the inner boundary of the upper wetlands, when such are present. This boundary also marks the lower edge of the coastal floodplain, which terminates where the coastal basin begins.

The shorelands all have potential "direct and significant impact on the coastal waters" (as stated in the Federal Coastal Zone Management Act) and must be included in the management program in order to protect coastal waters from pollution by sediment, nutrient, and toxic pollutants and to stabilize the volume and periodicity of the flow of freshwater into coastal water basins. There is an initial presumption of adverse impact of all land alteration in shorelands, and therefore all shorelands should be encompassed within the boundaries of the primary coastal zone management district. Subsequently, it may be discovered that portions of the defined shoreland area are not situated where they will have a significant influence (that is, to cause significant disturbance) on coastal waters, because of topographic or drainage details. Such shorelands should require no special constraints for the protection of coastal waters and may be excluded from many of the special management requirements.

The methodology for identifying watersheds and drawing watershed-divides in a shoreland area is essentially the same as for any area. For effective environmental planning it is desirable to delineate the smallest identifiable drainage basins as subwatersheds (Figure 6). Some of the flow may drain to channels, some to intermittent drainageways, and some directly to estuarine or ocean waters.

It is recommended that all freshwater areas, including all drainageways through the coastal watershed, be identified as Critical Environmental Areas. They are integral parts of the greater coastal water system and any disruption of them is presumed to be inimical to the functioning of the estuarine ecosystem. Also, it is recommended that the wetlands occurring within shore and water areas be designated as Vital Areas, exempt from alteration.

FRESHWATER WETLANDS

Freshwater wetlands in the coastal shoreland include vegetated areas that have saturated soils, are permanently flooded, or are flooded for a sufficient period each year to support communities (two or more species) of water dependent freshwater plants (hydrophilic plants). These wetlands include marshes, cypress domes, swamps, strands, bogs, sloughs, vegetated natural swales, and all other similar natural elements. It is a rather routine task for a botanist to identify freshwater indicator plants, to evaluate freshwater area vegetation communities and to locate boundary lines at the upper edge of freshwater wetlands (Table 1).

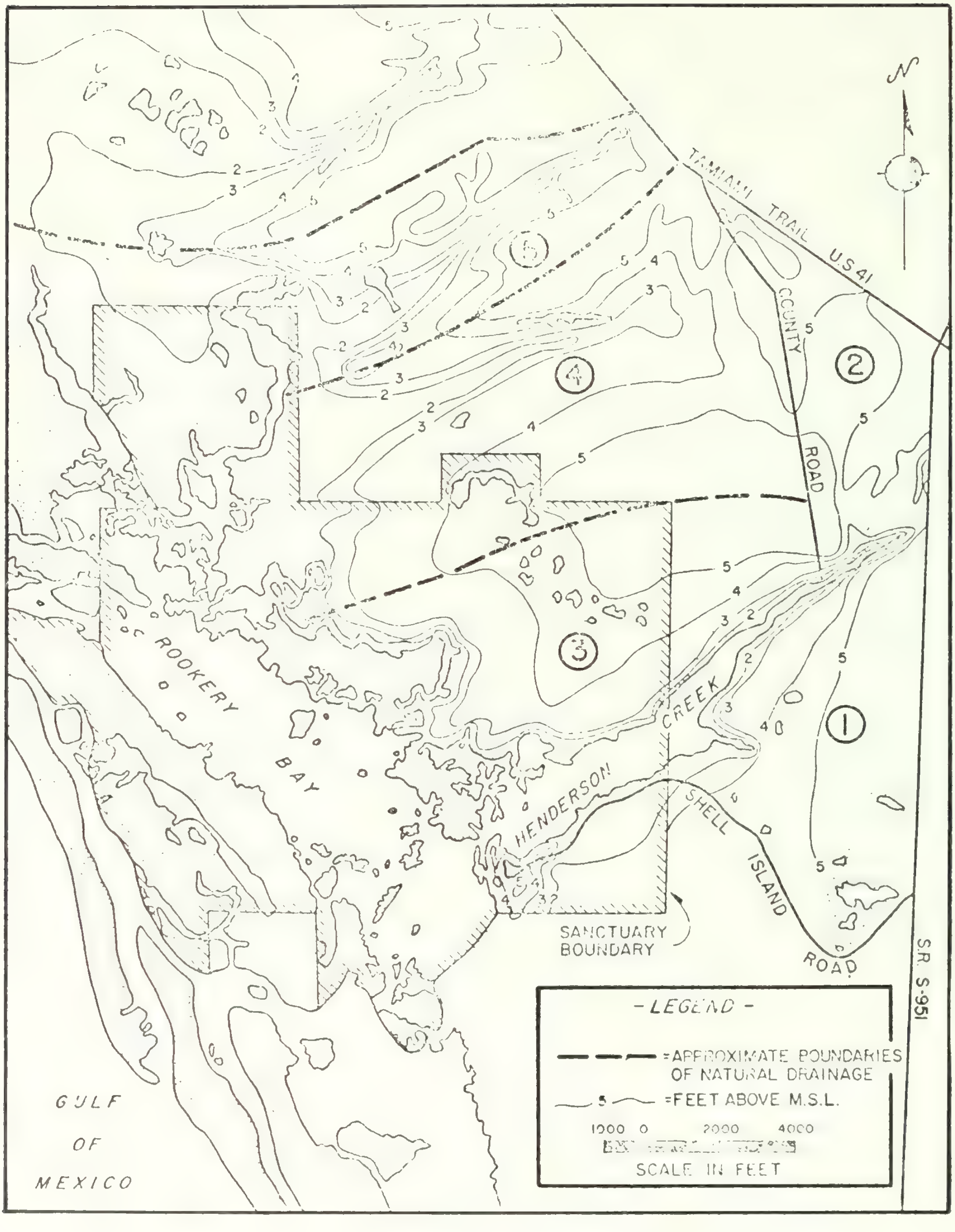


Figure 6. Drainage sub-basins that drain into the Rookery Bay estuarine system (Yokel 1973).

Vegetation will be the key to the location of shoreland drainageways which are to be protected to preserve the quality, volume, and rate of flow of runoff waters that discharge to coastal water basins. For example, in Florida, cypress (Taxodium distichum) trees are a reliable indicator of wet ground drainage areas. In each region there will be plant species, known to professional ecologists, that indicate drainageways.

The vegetative indicator system should identify the critical water areas as they exist presently and identify those previously drained or otherwise degraded but restorable, because many of the plants remain, even though they are not now capable of reproducing.

THE COASTAL FLOODPLAIN

The coastal floodplain is defined as the area lying along the lower margin of the shorelands, above the coastal wetlands or beaches, that is flooded with tidal waters at intervals of once or less per year (wetlands are defined as those areas flooded frequently; more than once a year, often daily). For general coastal zone management purposes, the upper edge of the coastal floodplain is defined as the 100-year mark (or 100-year storm return interval), the point on the land that represents the furthest inland extension of flood waters expected to occur once in 100 years. There also may be a need to locate boundaries of other "statistical" floodplains--the 10-year and 25-year marks--for uses in designating buffer areas and for excluding or controlling certain uses. The 1-year flood mark is particularly relevant because it marks the upper edge of the coastal wetlands.

Floodplain boundaries are set by various methods, none of which are particularly reliable for long storm-return intervals such as the 50- or 100-year storm, because accurate historical records are usually not available.

The basic technique for delineating the coastal floodplain is to determine from available data the relation between forces that drive storms (hurricane, northeaster, etc.), such as wind speed, and others that govern the moving impact of storm waters on the one hand, and those that govern storm surge elevations, the height of the water during flooding, measured from a basepoint, usually mean sea level, on the other hand. The surge elevation can then be projected back onto the shoreland topography and the line marking penetration drawn along the appropriate land elevation line. The surge elevation will vary greatly from place to place along the shore depending upon the shore alignment--funnel shaped configurations generally lead to the highest storm surges. Flood lines can be mapped for storm surges for any probability of occurrence--10-year, 25-year, or 100-year. The Federal Government is responsible for locating the 100-year flood mark in all coastal communities participating in the National Flood Insurance Program. The most difficult boundary location problems occur where inland floods and coastal floods intermix. There appears to be little or no theoretical base for predicting the high water mark where the two coincide. Salt tolerant vegetation, which is a good key to the coastal floods of a 1-year frequency, does not serve as a useful indicator of long-interval storms.

DUNES AND BEACHFRONTS

The delineation of dunes is complicated by two principal factors. First, because they are often quite mobile and do not remain in place, they require special surveying and inventory. Second, dunes come in a variety of shapes and sizes, and when they are small, flat ridges, as they often are, they are not easily distinguishable from other parts of the beach front. Dunes are most properly considered part of the shorelands (like floodplains) while the beach and associated berms are part of the coastal waters basin (being washed by tide waters at least annually).

Dunes and beaches require protective management and should be identified and classified for this purpose. The whole beach front should be designated an area of critical environmental concern, from the inner edge of the active duneline to the seaward extent of local community jurisdiction. The dunes themselves are classified as vital areas.

The dune system to be designated a vital area should always include the frontal dune and all active secondary dunes. Basically it should be defined as extending from the "toe" of the frontal dune or beach ridge, the place where significant vegetation begins, to the backside of the most inland active dune. An "active" dune is one that is mobile, or in the process of visibly gaining or losing sand; such a dune is usually vegetated mostly with grasses rather than woody vegetation.

A beach may be defined as the unvegetated part of the shoreline formed of loose material, usually sand, that extends from the upper berm to the low water mark. The typical beachfront complex is comprised of the following parts (Figure 7):

(1) Bar. An offshore ridge which is submerged permanently or at higher tides.

(2) Trough. A natural channel running between an offshore bar and the beach, or between offshore bars.

(3) Foreshore. The part of the shore lying between the crest of the most seaward berm and the ordinary low water mark that is ordinarily traversed by the uprush and backrush of the waves as the tides rise and fall.

(4) Backshore. The arm of the beach that is usually dry, that lies between the foreshore and the coastline, and is acted upon by waves only during storms and exceptionally high water.

(5) Berm. A ridge or ridges on the backshore of the beach, formed by the deposit of material by wave action, that marks the upper limit of ordinary high tides and wave wash. Berms have sharply sloping leading edges.

(6) Beach Ridge. A more or less continuous mound of beach material behind the berm that has been heaped up by wave action during extreme high water levels (if largely wind built, usually termed dunes, often vegetated).

(7) Dunes. More or less continuous mounds of loose windblown material, usually sand, behind the berm (often vegetated). The first layer dune is termed the foredune, or the frontal, or primary, dune; those behind the frontal dune are termed secondary, rear, or back dunes.

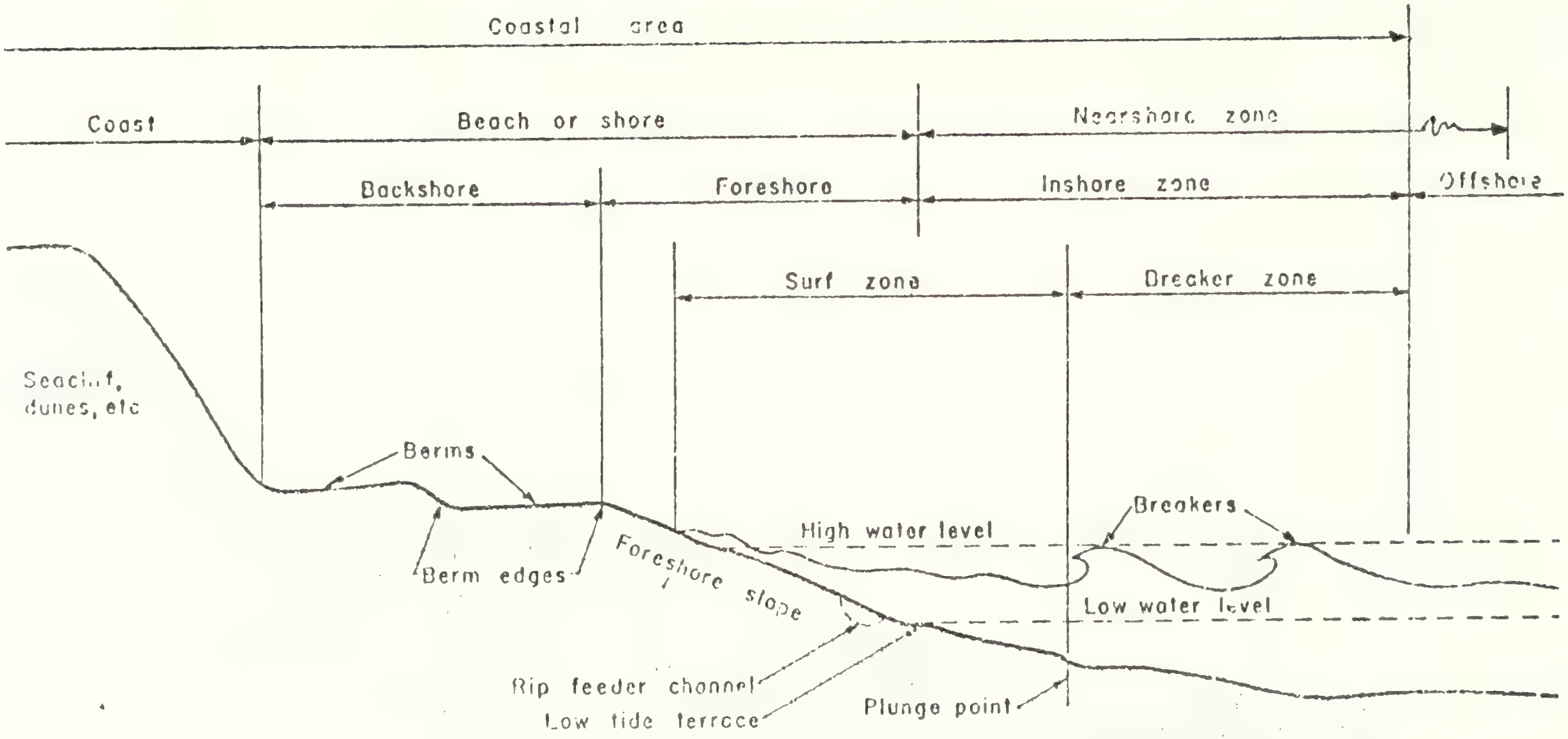


Figure 7. The anatomy of the beachfront (U.S. Army Corps of Engineers 1971).

The anatomy of the beach remains generally constant but its profile often shifts markedly with the seasons (Figure 8), particularly in response to winter storms. The berm-and-dune system acts as a buffer to the force of storm seas. As the dune is attacked by storm waves, eroded material is carried out and deposited offshore where it alters the shore profile. Accumulating sand decreases the offshore beach slope (makes it more nearly horizontal) thereby presenting a broader bottom surface to storm wave action. This surface absorbs or dissipates, through friction, an increasingly large amount of destructive wave energy which would otherwise focus on the beach. It is the capacity of the berm-and-dune system to store sand, and yield it to the adjacent submerged bottom, that gives it the outstanding ability to protect the shorelands. Low dunes have a lesser but nevertheless significant effect. Storm resistance increases with dune height, consequently, all human uses of the barrier which devegetate, erode, or lower the dune expose the shorelands to increased storm damage (Olsen and Grant 1973). An important exception is the overwash barrier beach which functions in a different fashion.

COASTAL WETLANDS

In the profile of the shore landscape, coastal wetlands are recognized as areas subject to flooding by brackish or salty water and which are naturally vegetated with salt tolerant plants (Figure 9). These plants occur in communities variously dominated by certain types of grasses, rushes, and other salt-tolerant species, including mangrove trees in subtropics and tropics. Soils may also be indicative of wetland areas but they do not serve this role as readiliy or practicably as vegetation. The coastal wetlands are identified as vital areas because they play such a valuable and critical role in the functioning of coastal ecosystems and the maintenance of a high level of carrying capacity.

Because of the changing relative influence of various governing factors, there is a graduation in plant species from the lowest elevation of the wetlands up the slope to the upper boundary of the wetlands. It is relatively easy to find the point above which there is no significant growth of saltwater tolerant plants. This point would be the inner boundary of the coastal waters, as well as the wetlands, and approximates the annual flood mark or annual storm line, the point of the highest expected yearly storm surge.

The particulars of zonation vary from one coastal area to another depending upon the influence of a wide variety of natural conditions. Often the position of the boundary between the wetlands and the upland will be controversial because any possible private property holdings below the boundary will be subject to strict controls on use.

It is convenient to distinguish between the lower wetlands (vegetated tidelands) and the upper wetlands because they are often quite different in form, vegetation, function, and in the application of environmental regulations. The lower wetlands extend from the low water mark up to about the mean high water mark. The upper wetlands extend from about the mean high water mark up to the annual flood mark (Figure 10).

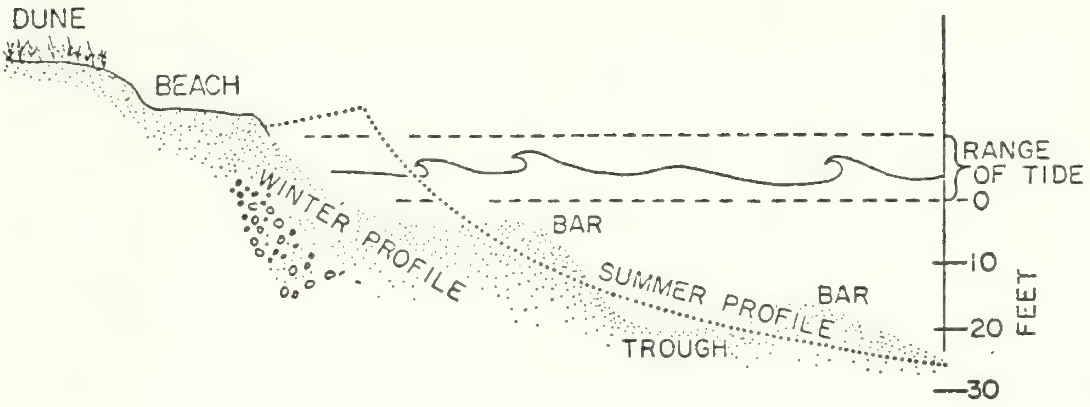


Figure 8. Winter and summer beach profiles (Olsen and Grant 1973).

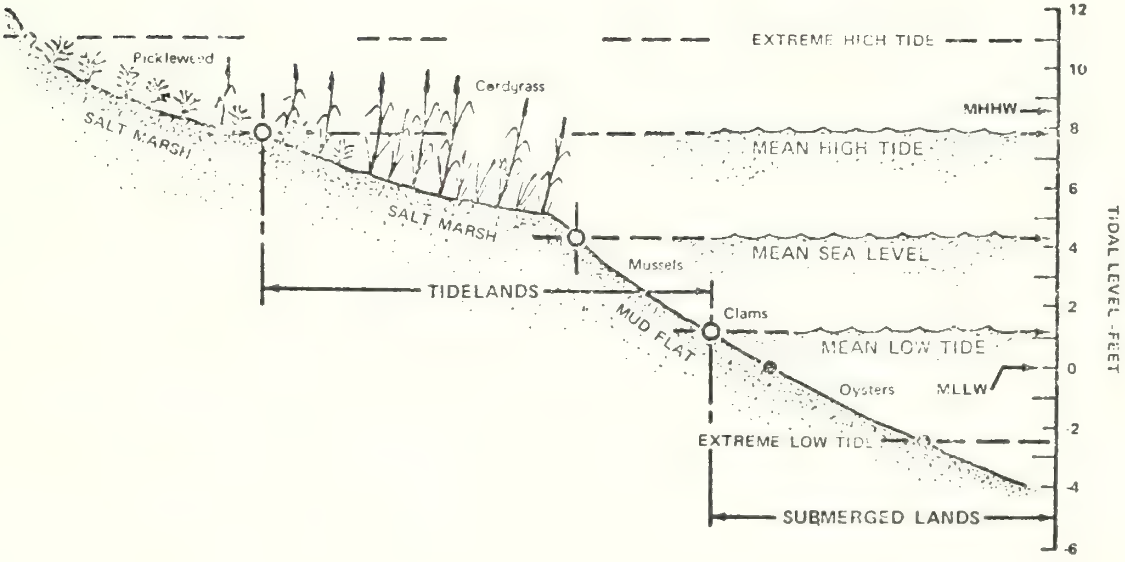


Figure 9. Profile of a California wetlands shoreline.

The *upper wetlands* are naturally vegetated with salt tolerant plants that prosper in the wet soils of the high marsh. Because they form the marginal zone of the estuarine water basin, when present, their landward edge is the boundary between the coastal waters province and the shorelands province. Immediately above the wetlands lie the floodplains, the lower, marginal zone of the shorelands. The line of demarcation between the two marginal zones, and therefore between shorelands and estuary, is readily identified by the sharp change in plant species near the annual storm highwater ecotone of the marsh. For example, the upper edge of the salt bush marsh-elder (*Iva frutescens*), clearly marks the boundary of coastal wetlands in many areas (Figure 11).

The lower wetlands extend from the high water mark down to the low water mark ("low water mark" and "high water mark" are used in a deliberately general sense because the exact tidal reference varies from place to place and the boundary between upper and lower wetlands is more a zone than a line.) The boundary between lower and upper wetlands is distinguishable by a change in species or of the *vigor* of species (height, color, size of leaf or blade). The lower wetlands are most often dominated by a species of *Spartina* grass, such as S. *alterniflora*, or of red mangrove such as *Rhizophora mangle*.

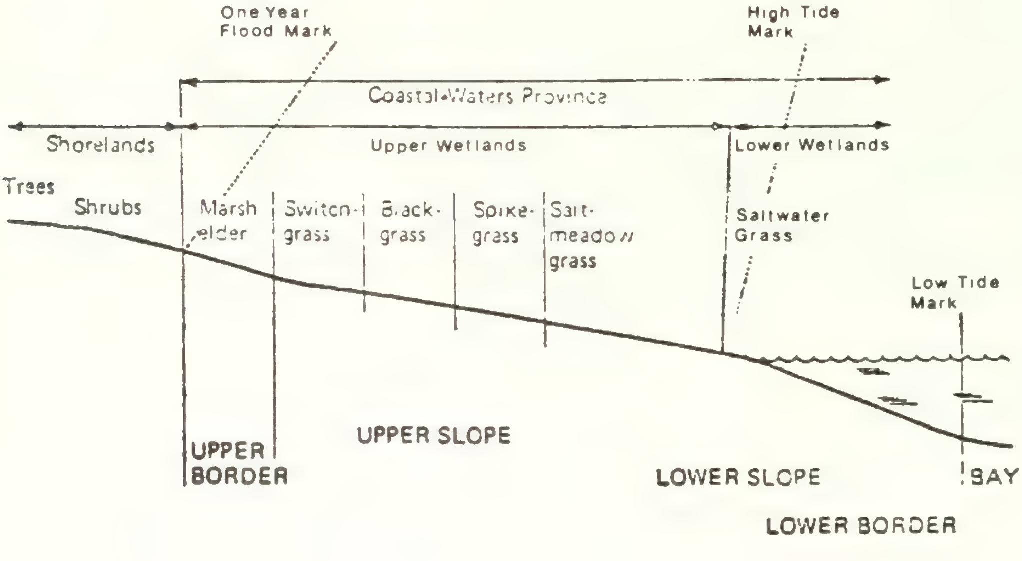


Figure 10. Vegetative zonation of a typical southern New England marsh shore (adapted from Roberts 1971).

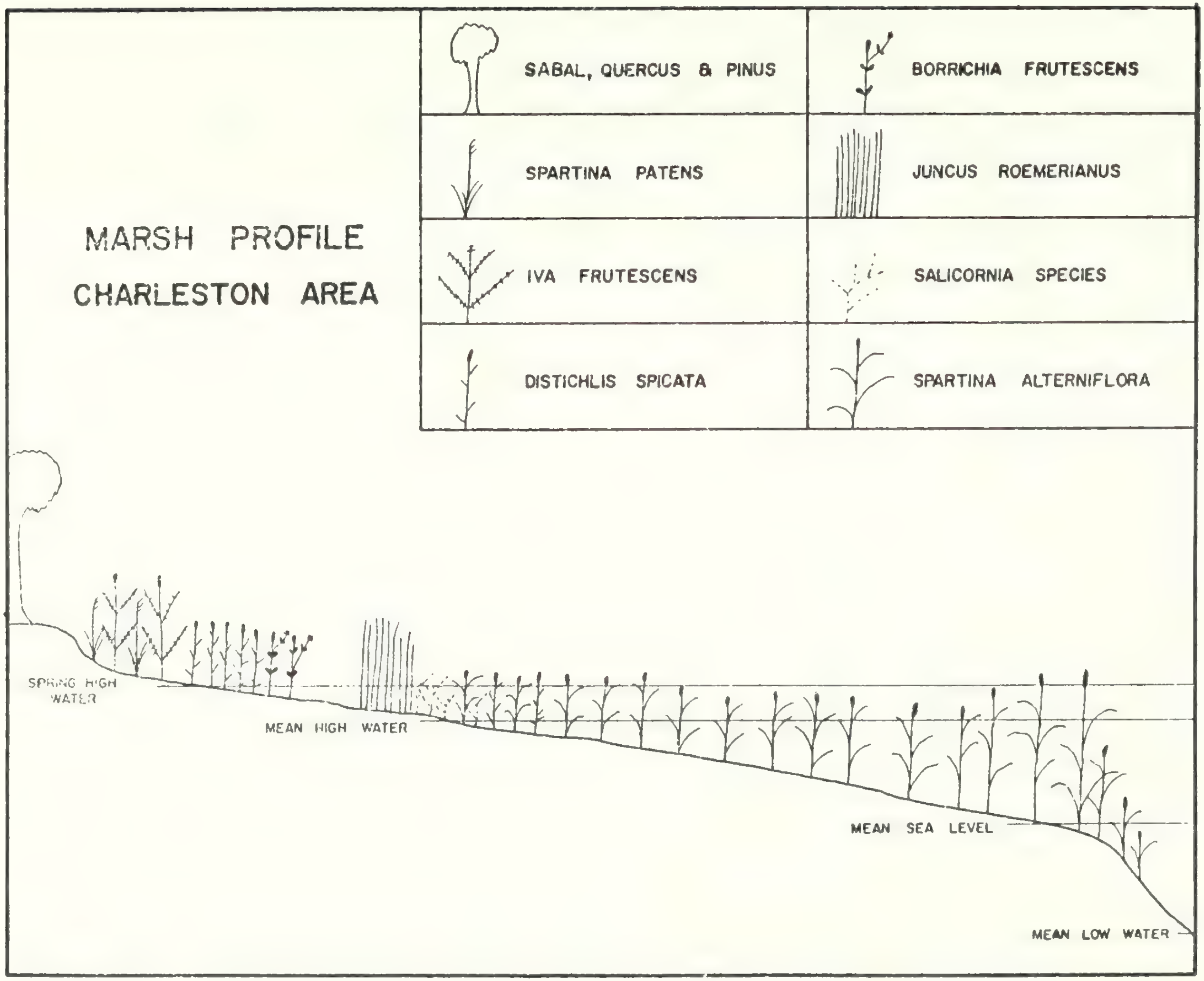


Figure 11. Typical transect of tidal salt marsh in Charleston Harbor Estuary (Office of Marine Conservation, 1972).

LITERATURE CITED

Clark, J.R., 1974. Rookery Bay: Ecological Constraints on Coastal Development. The Conserv. Found., Washington, D.C.

Clark, J.R., 1977. Coastal Ecosystem Management: A Technical Manual for the Conservation of Coastal Zone Resources. John Wiley-Interscience, Somerset, New Jersey.

Gagliano, S.M., 1973. Canals, Dredging, and Land Reclamation in the Louisiana Coastal Zone. Rep. 14, Hydrologic and Geologic Studies of Coastal Louisiana. Cent. for Wetland Resour. Louisiana State Univ., Baton Rouge.

Goldman, H.B., 1973. Hayward Shoreline Environmental Analysis. Hayward Area Shoreline Planning Agency, Hayward, California.

Office of Marine Conservation. Management and Services. 1972. A Study of the Charleston Harbor Estuary with Special Reference to Deposition of Dredged Sediments. South Carolina Wild. and Marine Resour. Dept., Marine Resour. Cent., Charleston.

Olsen, S.B. and M.J. Grant. 1973. Rhode Island Barrier Beaches. Vol. I. Coastal Resour. Cent. Univ. Rhode Island, Kingston.

Roberts, M.F., 1971. Tidal Marshes of Connecticut. Rep. Ser. 1. The Connecticut Arboretum, Connecticut College, New London.

Smith, E.M. and R.D. Wood. 1973. The Salinity Gradient and Vegetation in the Saugatucket River Estuary. Marine Tech. Rep. Ser. 6, Univ. Rhode Island, Kingston.

U.S. Army Corps of Engineers. 1971. Hawaii Regional Inventory of the National Shoreline Study. Pacific Ocean Div. U.S. Army Corps of Engineers, Honolulu, Hawaii.

Veri, A.R., A.R. Marshall, S.U. Wilson, J.H. Hartwell, P. Rosendahl, and T. Mumford. 1973. The Resource Buffer Plan: A Conceptual Land Use Study Water Management District 6, Collier County, Florida. Study 2, Rookery Bay Land Use Studies. The Conserv. Found., Washington, D.C.

Wallace, McHarg, Roberts and Todd, Planning Consultants. 1975. Comprehensive Land Use Plan: City of Sanibel, Lee County, Florida. Rep. to the Sanibel Planning Comm. Philadelphia, Pennsylvania.

Yokel, B.J. 1973. Estuarine Water Quality. Rookery Bay Land Use Studies. Study 3. The Conservation Foundation, Washington, D.C.

INSULAR AQUATIC ECOSYSTEMS: HAWAII

J.A. Maciolek
U.S. Fish and Wildlife Service
Hawaii Cooperative Fishery Research Unit
2538 The Mall, University of Hawaii, Honolulu

Abstract: Extensive field studies by the Hawaii Cooperative Fishery Research Unit provided a basis for a provisional, functional classification of all Hawaiian surface waters exclusive of the marine ecological system. Traditional physicochemical features and characteristic biota are employed in the designation of 14 ecosystem types comprising 4 flowing water types, 3 lacustrine types, 4 palustrine (wetland) types, 2 estuarine types, and a unique mixohaline coastal ecosystem in recent lava fields--anchialine pools. Eight of the types are freshwater, and 6 are mixohaline; 11 of them are natural and 3 are manmade. Abundance of each type, mostly estimated, is given. Appendix information includes descriptive summaries of environmental features and biota of each ecosystem, and their distributions are shown on maps of the five largest islands.

INTRODUCTION

The Hawaiian Archipelago is an isolated and diverse group of oceanic islands ranging from coral atolls to a glaciated volcanic high island. Its aquatic ecosystems, with particular reference to inland waters, are equally diverse. Recent geographic classifications of natural living resources recognized the Hawaiian Archipelago as a distinct locality. It has been identified by the International Union for the Conservation of Nature (IUCN 1974) as Biotic Province 6. 12. 23., a Mixed Island Systems biome of the Australian Biogeographic Region. Another international scheme relating to marine and coastal classification (Ray 1975) designated Hawaii zoogeographically as I. A. 3., one of several Indo-West Pacific Subprovinces of the Tropical Warm Water Shelf Province. In aquatic classification of national scope, Cowardin et al. (1976) listed Hawaii as one of 10 biogeographical provinces, the Pacific Insular Province.

Ecological resource classification is independent of geography in broad concept, but distinguishable regional variations or differences in ecosystems occur, as recognized by Cowardin et al. (1976). However, the aquatic classification scheme presented by those authors does not apply well to Hawaii because its perspective is continental and largely botanical. A detailed ecological classification for archipelagos of the South Pacific Commission by Dahl (1976) includes aquatic ecosystems, but Dahl's categories for inland waters, also botanically based, are not all mutually exclusive (some are minor components of ecosystems) and therefore are useful descriptively but not operationally.

A resume of prominent natural Hawaiian inland water ecosystems has been published (Maciolek 1975). The present effort is more detailed; proposed here is a comprehensive, applied classification of all ecologically significant inland surface waters (defined as waters not primarily marine or directly part of marine ecosystems). Comprehensiveness refers to the inclusion of all permanent and intermittent waters (natural, artificial, or culturally modified), and also to estimates of numbers of ecosystem types and their geographical distributions. This classification originated as a contribution to a multi-agency committee effort to revise State water quality standards on an ecosystem basis. Its potential application includes various other agencies, as well as individuals who have use for an insular regional classification of aquatic ecosystems. Descriptive information and geographical distributions were obtained in part from references listed and in part from unpublished data of the Hawaii Cooperative Fishery Research Unit.

TERMINOLOGY AND CRITERIA

Terminology presents a persistent problem in classification schemes. Different classifiers appear to employ some key ecological terms (e.g., "habitat") in different contexts, and often discuss such terms without providing the needed operational or pragmatic definitions. Much of the problem revolves about the different interdisciplinary connotation of ecological terms, such as between terrestrial and aquatic ecologists (see discussion in Hutchinson 1967, Chapter 19). Indeed, individual biologists in the same field may not agree completely on the meaning of all frequently used ecological expressions. Perhaps different terminology, or at least different definitions, should be applied to separate discipline elements of a broad ecological classification scheme. For the present, it remains incumbent on each classifier to attempt to provide operational definitions of important terms, even though they may not be fully acceptable to the entire audience.

The following definitions apply to the present classification of Hawaiian inland waters. The aquatic ecosystem is the principal coherent subunit of the aquatic biosphere, consisting of a watermass continuum with relatively sharp, delineable boundaries (ecotones), enclosing integral resident organisms and physiochemical features. Examples of common aquatic ecosystems are lakes, marshes, streams, and estuaries. Two basic components of an ecosystem are the biota (biocoenosis) or totality of living matter[1], and the environment which is here restricted to the nonliving (physicochemical) components of the ecosystem, including spatial dimensions. Habitat is used strictly in an autecological sense to designate all ecosystem requirements of a species, including space. Thus, habitats are not spatially exclusive subdivisions of an ecosystem, as are zones, strata, reaches, etc.

Various types of aquatic ecosystems are assigned to major divisions or classes which are the "Ecological Systems" of Cowardin et al. (1976) with three exceptions: (1) the "Marine" Ecological System is excluded from this classification; (2) Anchialine, a unique ecosystem class (discussed later), is introduced; and (3) Lotic is substituted for "Riverine", a word which connotes large ecosystems of specific type and also is etymologically aberrant with the classical derivations of other class names. "Lotic" fully covers the diversity of flowing water ecosystems (discussed later) recognized herein but not by Cowardin et al. (1976).

---

[1] In this context, communities are subunits openly definable as assemblages of organisms (such as plankton, nekton, and benthos) sharing common space or special features, and sometimes divided as major taxons.

Implicit here is that ecosystem designation must be based on descriptions of both characteristic biota and environmental features. Ideally, ecosystem categories should be mutually exclusive, each readily discernible by observation and measurements that do not require a protracted time interval to accomplish. Criteria used to distinguish ecosystems classes are hydrological regime, water depth, salinity, and characteristic major taxons of biota (usually, the fauna is more distinctive than the flora). Ecosystem types are defined by criteria that include altitude, topography, water character (temperature, pH, turbidity), cultural influences (environmental and biological), and individual genera or species. After reviewing chemical data, I concluded that oxygen content and pH usually cannot be applied at the ecosystem level. In many waters, particularly those of low ionic content and abundant flora, strong phytosynthesis and respiration diurnally change the levels of such characteristics significantly (pH sometimes more than two units). Criteria are defined further in Appendix A.

ECOSYSTEM CLASSIFICATION

Fourteen types of inland aquatic ecosystems, occurring almost exclusively on the major high islands of the Hawaiian Archipelago, are listed and qualified in Table 1. These ecosystems (underscored below) are grouped into five ecosystem classes: Lotic, Lacustrine, Palustrine, Estuarine, and Anchialine. Brief descriptions follow. Defining features are given in Appendix B and general map locations in Appendix C.

The Lotic Ecological System contains four types of flowing waters. Perennial Streams forms the largest (by area) and most widely distributed type of ecosystem in Hawaii. In a nearly completed statewide inventory, Timbol and Maciolek (1976) listed 334 streams. Several more have been added recently to the inventory and the final tally is expected to be near 360. These streams are distinguished by three endemic diadromous gobies and a mollusk that live as adults in no other ecosystem. Intermittent Streams differ environmentally in flow regime, and biologically in lacking diadromous fauna, but contain abundant small invertebrates such as ostracods that elsewhere are rare. Rheocrenes are numerous, ubiquitous small seepages ("leaks" from elevated aquifers) without channels that provide habitat for endemic lymnaeid snails and other invertebrates (e.g., damselfly naiads). Ditches and Flumes are artificial streams in which some animals are native but most are exotic. Some ditches were built by ancient Hawaiians for taro irrigation; most were constructed during the past century for sugar cane irrigation. They occur on all major islands but have not been inventoried.

The Lacustrine Ecological System is represented by a few natural and many artificial deepwater basins. Only four freshwater Natural Lakes are known, their occurrence limited by substratum permeability (Maciolek 1969). Each is distinctive in location, environmental features, and native invertebrate fauna. Reservoirs (impoundments) are the most abundant lacustrine ecosystem; more than 400 are shown on quadrangle maps of the U.S. Geological Survey. They are artificial ecosystems, not only in basin origin and structure but also in biota, which is dominated by introduced macrofauna. Two Saline/Haline Lakes constitute a rare ecosystem type in Hawaii, one being a high-island shoreline feature and the other a flat-island closed lagoon. They are mutually distinct and could be classified as separate ecosystem types.

Table 1. Hawaiian Inland Water Ecosystems: Distribution, Abundance, and Fauna

Ecosystem Class	Location (Island)[a]	Elevation (m; SL = Sea level)	Approximate Number	Characteristic Fauna (N = native, I = introduced)
1. LOTIC (RIVERINE)				
1a. Perennial Streams	All	<2000	360	N: diadromous fishes, invertebrates
1b. Intermittent Streams	All	Various	>100	N: ostracods, beetles
1c. Rheocrenes	All	<1000	>1000	N: snails, damselflies
1d. Ditches and Flumes	K,Ma,O	< 500	>200	N/I: dipterous larvae, fishes
2. LACUSTRINE				
2.1 Limnetic (fresh)				
2.1a Natural Lakes	--	Various	4	N/I: small invertebrates
2.1b Reservoirs	K,Ma,O	< 1000	400	I: fishes, crayfish
2.2 Saline/Haline	--	SL	2	N: various
3. PALUSTRINE				
3.1 Elevated Wetlands				
3.1a Montane Bogs	All[b]	600-2000	8 areas	N: odonates, beetles
3.1b Ponds and Marshes	K,H	100-1200	5 areas	N: odonates, beetles, cladocerans
3.2 Low Wetlands				
3.2a Limnetic Wetlands	K,Ma,O	SL	>10 areas	I: topminnows, crayfish, tadpoles
3.2b Saline Wetlands	All	SL	25 areas	I/N: snails, insects, tilapia
4. ESTUARINE				
4a. Natural Estuaries	K,H	SL	20	N/I: euryhaline fishes, crustaceans
4b. Developed Estuaries	H,Mo,O	SL	10	I/N: fishes, crustaceans, worms
5. ANCHIALINE (Pools)	H,Ma	SL	30 areas	N: snails, hypogeal shrimps

[a] Islands were most abundant: H = Hawaii, K = Kauai, Ma = Maui, Mo = Molokai, O = Oahu
[b] Also Playa "Lakes," Island of Niihau.

The Palustrine Ecological System includes various wetlands initially subdivided into interior-elevated and coastal-lowland ecosystems, each with two types. Elevated wetlands, located in remote areas, are mainly natural ecosystems in which native biota dominates; low wetlands have been modified severely by man although they still constitute the primary habitat for most native waterbirds. *Montaine Bogs* occur in limited sites on all high islands and are distinguished by strongly acid waters and impoverished invertebrate fauna. *Elevated Ponds and Marshes* appear more productive than bogs and have greater faunal diversity. Further study might show that these two types form a graded series classifiable as a single ecosystem type. Introduced biota predominates in *Limnetic Low Wetlands*, a complexity of similar ecosystems ranging from flooded taro fields to natural marsh basins. *Saline Low Wetlands* are shoreline salt marshes and ponds that originated artificially (abandoned Hawaiian fishponds, recently constructed waterbird refuges) or naturally (perennial and seasonal wetlands, Maciolek 1971). Salt-dependent pickleweed (*Batis maritima*) is a common emergent plant; fauna includes introduced euryhaline fishes and invertebrates co-occurring with native snails and isopods. Present day aquaculture ponds can be fitted into either of the above types of coastal-lowland ecosystems.

The Estuarine Ecological System is restricted to mixohaline tidal waters in distinct basins that have sufficient surface connection to the ocean for frequent or periodic migration of euryhaline marine fauna. *Natural Estuaries*, most of which occur on Kauai, serve as nurseries for mullet and kuhliid fishes and harbor various other native fishes, mollusks, and crustaceans. Common introduced animals include *Scylla* crabs and tilapia. Two subtypes, drowned river mouths and estuarine limnocrenes are similar in environmental conditions and resident fauna, but drowned river mouths receive stream runoff and thus are important as migratory routes for diadromous fauna. *Developed Estuaries* include basins that are manmade (e.g., dredged or channelized stream mouths) or developed from a natural state. Fauna is similar to that in Natural Estuaries but is usually less diverse, except in some Hawaiian fishponds (structure described in Kikuchi 1976) that biologically resemble estuarine limnocrenes.

The Anchialine Ecological System consists of a single type, *Anchialine Pools*. The name (from Greek *Anchialos*, "near the sea") was suggested by Holthuis (1973) to define "pools with no surface connection with the sea, containing salt or brackish water, which fluctuates with the tides." Ecosystem definition should note further that distinctive biota includes invertebrate species not found elsewhere. Anchialine Pools occur in various insular and continental locations but within the United States they appear to be uniquely Hawaiian. Most are in recent coastal lava fields on Maui and Hawaii islands. Kona Coast sites containing anchialine pools and other ecosystem types were inventoried and described by Maciolek and Brock (1974). Most pools are small, 90 percent being less than 100 m^2 in area. Surfaces are inland extensions of the oceanic water table. Mixohalinity, usually less than 10 percent, results from dilution by seaward percolating groundwater. Mat- and crust-forming algal communities occur in rocky pools, and widgeongrass (*Ruppia maritima*) is characteristic in sedimented basins. The fauna, which includes many endemic species, consists mostly of invertebrates of marine origin that invaded through subterranean interstices. Characteristic taxons are snails, amphipods, and shrimps; fishes are absent or rare.

CLASSIFICATION DEFICIENCIES AND ENIGMAS

Any comprehensive classification scheme, designed for practical application and encompassing diverse ecosystems that are sometimes transitional, is fundamentally provisional. Its completeness and utility are relative, reflecting the accuracy, extensiveness, and recency of data on which it is based. Relevant data are never fully adequate. Thus, each ecosystem described can be rated on the "strength" of its informational base. Perennial Streams are best qualified in the present classification as a result of extensive biological surveys, and data on flow and water quality generated from the continuing monitoring program of the U.S. Geological Survey (e.g., USGS 1976). Data bases for Anchialine Pools and Natural Lakes are good, but further information on them is desirable. Additional data would materially improve descriptions on the other ecosystem types. Least well qualified in this classification are artificial and culturally modified ecosystems such as Reservoirs, Ditches, and Developed Estuaries.

Assuming that natural quality of the ecosystem is important in a classification scheme, Hawaii has a serious problem in the growing influence of human culture on both the environment and biota. Stream channelization and water diversion, for example, degrade part of the native ecosystem physically and biologically. More than half of Oahu's 54 streams have channel alterations. Approximately 60 percent of all Hawaiian streams have diversions or channel alterations. How extensively must a given stream be channelized or diverted before it is classified as an artificial ecosystem? Furthermore, man has caused establishment of foreign species to the extent that they outnumber native species among the freshwater macrofauna. Recent biological surveys indicate that all lowland limnetic ecosystems on Oahu are dominated in species numbers and biomass, by exotics. Some exotics spread so slowly that it will be many years before biota equilibrium is approached statewide, even if further introductions could somehow be halted. Should we treat these situations as successional phenomena or should we design two classification schemes, drawing a line between natural and artificial ecosystems in all categories?

The Hawaii Department of Health, in a proposed revision of water quality standards based on ecosystem types, recognizes five "status-use" categories with differing levels of certain water quality parameters into which all surface waters are assigned. Relative natural quality is one of the factors used in assigning a given ecosystem into a category. Such an approach involves considerable subjective judgment and requires periodic reevaluation of many ecosystems that in time could degrade or improve in natural quality.

LITERATURE CITED

Cowardin, L., V. Carter, F. Golet, and E. LaRoe. 1976. Interim Classification of Wetlands and Aquatic Habitats of the United States. Addendum to J. Sather, ed., Proc. Natl. Wetland Classification and Inventory Workshop. U.S. Dept. Inter., Fish Wildl. Serv., OBS-76/09.

Dahl, A. 1976. Regional Ecosystems Survey of the South Pacific area. South Pac. Comm. and Int. Union Conserv. Nature, 2nd Regional Symp. Conserv. Nature, Apia, W. Samoa, Working Pap. 1. 102 pp.

Holthuis, L. 1973. Caridian shrimps found in land-locked saltwater pools at four Indo-West Pacific localities (Sinai Peninsula, Funafuti Atoll, Maui and Hawaii Islands), with the description of one new genus and four new species. Zool. Verh. 128:1-48.

Hutchinson, G. 1967. A Treatise on Limnology. Vol. II. Introduction to Lake/Biology and the Limnoplankton. John Wiley and Sons, Inc., New York. 1,116 pp.

IUCN. 1974. Biotic Provinces of the World. Int. Union Cons. Nature Man and Biosphere Program Proj. 8, Occas. Pap. 9. 57 pp.

Kikuchi, W. 1976. Prehistoric Hawaiian Fishponds. Science 193:295-299.

Maciolek, J. 1969. Freshwater lakes in Hawaii. Verh. Int. Ver. Limnol. 17:386-391.

Maciolek, J. 1971. Aquatic ecosystems of Kealia floodplain and Maalaea Bay, Maui. Univ. Hawaii Inst. Marine Biol. Tech. Rep. 27. 42 pp.

Maciolek, J. 1975. Limnological ecosystems and Hawaii's preservational planning. Verh. Int. Ver. Limnol. 19:1461-1467.

Maciolek, J., and R. Brock. 1974. Aquatic Survey of the Kona Coast Ponds, Hawaii Island. Univ. Hawaii Sea Grant Adv. Rep., UNIHI-SEAGRANT-AR-74-04. 73 pp.

Ray, G. 1975. A Preliminary Classification of Coastal and Marine Environments. Int. Union Cons. Nature Occas. Pap. 14. 26 pp.

Timbol, A., and J. Maciolek. 1976. Stream Channel Modification (Channelization) in Hawaii and its Environmental Effects on Native Fauna. Part A. Statewide Inventory of Channelization with Preliminary Survey of Environmental Factors and Associated Biota. Annu. Rep., Univ. Hawaii-U.S. Fish. Wildl. Serv. Contract 14-16-0008-1199. 127 pp.

U.S. Geological Survey. 1976. Water Resources Data for Hawaii and Other Pacific areas, 1975. Water-Data Rep. HI-75-1. 418 pp.

APPENDIX A

DEFINITIONS OF TERMS AND UNITS

1. Dimensions.

°/°° = parts per thousand, measure of salinity.
% gradient = relative slope measured as unit elevational change per 100 horizontal units (as m/100 m).
μmhos = reciprocal megohms, measure of water conductivity.
Also: distances, areas, volumes, etc. given in metric system; temperatures in ° Celsius.

2. Water Regimes.

Lentic = standing or still water as in ponds, reservoirs, etc.
Lotic = flowing water as in streams, springs, etc. Refers to unidirectional gravitational flow, thereby excluding waters moving with wind currents, waves, and tides.

3. Dissolved Minerals.

a. Qualitative aspects.
Haline (halinity) = brackish or salty water condition wherein dissolved ions are derived from seawater.
Saline (salinity) = general term for water with noticeable salt content; ions from various sources.

b. Quantitative aspects.

Limnetic = freshwater, salt content <0.5 °/°°.

Mixohaline = brackish water, salt content 0.5 to 30 °/°°.

Euhaline = seawater, salt content 30-40 °/°°.

Hyperhaline = brine-like water, salt content >40 °/°°.

c. Concentration vs. time.
Homoiohaline = salt concentration stable or fluctuating over narrow range.
Poikilohaline = salt concentration fluctuating widely.

d. Biological response.
Euryhaline = tolerates wide range of salt concentration.
Stenohaline = tolerance limited to narrrow range of salt concentration.

4. Faunal Life History.

Diadromous = two migrations; refers to an aquatic animal that obligately spends parts of its life in different ecosystems (eg. a Hawaiian stream dweller that undergoes larval development in the ocean).

APPENDIX B

HAWAIIAN INLAND WATERS: DESCRIPTIVE FEATURES AND CHARACTERISTIC BIOTA.

1. LOTIC (RIVERINE) ECOLOGICAL SYSTEMS.

Limnetic surface waters flowing unidirectionally down altitudinal gradients.

1a. Perennial Streams. Waters draining land surfaces in discrete channels and flowing year-round. Upper altitudinal limit. ca. 2,000 m, fixed by orographic rainfall regime. Turbidity low except during freshets; dissolved oxygen normally near saturation throughout watercourse. Flora mainly mosses, filamentous algae, and epilithic diatoms. Native macrofauna (fishes, shrimps, mollusk) diadromous, with marine larval development. Prominent altitudinal zonation of environmental conditions and biota.

Headwater Reach. Elevation >800 m or gradient >30%, or both. Substratum mainly bedrock. Water: temperature <18° (usually 12-15°); conductivity <50 μmhos (dissolved solids <40 mg/l); pH usually <5.5. Fauna primarily native: aquatic insects (Coleoptera, Diptera, Odonata) and lower invertebrates; no decapod crustaceans or native fishes.

Midreach. Intermediate in environmental conditions between Headwater and Terminal Reaches (see below). Substratum predominantly boulders. Native fauna: atyid shrimp, riffle midges, lymnaeid and neritid snails, true gobies (especially *Lentipes* and *Sicydium*); no eleotrid or itinerant marine fishes. Introduced fauna: caddisfly, Tahitian prawn, crayfish, and several fishes (especially tilapia, topminnows, loach).

Terminal Reach. Watercourse below sharp gradient that bars upstream migration of itinerant marine fishes--elevation generally <50 m and gradient <5%. Substratum: rock, gravel, and sediment. Water, except during freshets: temperature >18° (mainly 19-22°); conductivity >80 μmhos (mainly 100-150 μmhos); dissolved solids 60-100 mg/l; pH 6.5-7.8. Native fauna: midge and cranefly larvae, snails (*Melania*, *Neritina*), prawn, gobioid and itinerant marine fishes (*Eleotris*, *Kuhlia*, and *Mugil*). Introduced fauna: crayfish, Tahitian prawn, topminnows, tilapia, and clariid catfish.

Remarks: More than 360 perennial streams identified, all major islands (localities, Appendix C); largest = Wailuku River, Hawaii--35 km long, 350 km^2 drainage area, 8 m^3/s (285 cfs) mean discharge. Most streams originally discharged continuously to ocean; some small interrupted streams discharge only seasonally but flow perennially in upper reaches. Most streams diverted for agricultural and domestic purposes; total normal flow diverted from many streams (Oahu, Maui), rendering them artificially interrupted. Channel alteration (16% of all streams) modifies or eliminates native ecosystem character, particularly in Honolulu area. Oahu's streams dominated by introduced fauna. Few relatively pristine streams remain in archipelago, mainly on the remote windward slopes of Kauai, Molokai, and Hawaii (Kohala District) Islands.

1b. Intermittent Streams. Seasonally flowing waters draining land surfaces in discrete channels (gulches or wadis). Water quality variable. Characteristic biota appearing where water persists for at least a few weeks (usually as diminishing flow): filamentous algae, oligochaete worms, *Ancylus* limpets, ostracods, beetles, backswimmers. No diadromous fauna. Occur on dry (leeward) slopes of all islands and porous wet slopes (recent lava, e.g., Hualalai and Mauna Loa, Hawaii). Some occur at elevations above 2,000 m (eg. Pohakuloa Gulch, Mauna Kea; Pulehu Gulch, Haleakala).

1c. Rheocrenes. "Flowing spring." Perennial seeps and springs flowing short distances over rock surfaces or in indistinct channels. Found typically along banks of deeply incised streams or coastal rock faces (especially windward coasts of Kauai, Molokai, East Maui). Variable water quality, sometimes iron-rich as evidenced by bacterial precipitation of ferric hydroxide. Characteristic biota: gelatinous (blue-green) algae, mosses, maidenhair fern, detritivorous leeches, (Diptera, Odonata), lymnaeid snails.

1d. Ditches and Flumes. Water flowing continuously in artificial channels. Environmental character and biota vary with location and degree of use. Primary Ditches/Flumes carry diverted stream water to reservoirs or use areas. Generally high-quality water like that in stream at diversion point (most located 100-500 m elevation, comparable to midreach stream water). Lack of shelter and slack water results in low faunal diversity; most prominent are aquatic fly larvae, snails, and sometimes atyid shrimp. Fishes scarce. Primary ditches abundant on Kauai, Oahu, Maui, and Hawaii (Kohala District) Islands. Secondary (or effluent) Ditches carry water from reservoirs, agricultural sites, and use facilities. Moderate to low water quality, sometimes polysaprobic. Macrofauna, when present, consists mainly of introduced fishes and tolerant invertebrates. Mostly at elevations below 50 m.

2. LACUSTRINE ECOLOGICAL SYSTEMS.
Lentic water in definite basins with predominant open water and depth exceeding 2 m.

2.1. Limnetic water, salinity <0.5 °/₀₀

2.1a. Natural Lakes. Uncommon in Hawaii. Four small lakes known: Waiau and Green, Hawaii; Waiele'ele, Maui; and Meyer, Molokai (Appendix C). Range in elevation from 3,969 m to near sea level. Individually distinctive environmental character and biota. Native fauna: small invertebrates (no fishes, shrimps). Exotic fishes introduced into two lakes.

2.1b. Reservoirs. Artificial water bodies constructed for irrigation and other socioeconomic purposes. Low to intermediate altitudes (<1,000 m) principally on Kauai, Oahu, Maui, and Hawaii (Appendix C). Surface area <1 to 104 ha (Waita, Kauai). Not inhabited by native fauna. Environmental quality and biota vary with reservoir type.

Primary Storage Reservoirs. Primarily for agricultural and domestic water supply. Water bodies near source streams in remote upland sites. Relatively stable surface levels and good water quality. Some with submersed and floating water flora. Fauna: crayfish, sport fishes (especially largemouth bass, bluegill, catfish), topminnows, tilapia, insects.

Distributional Reservoirs. Water bodies mainly on agricultural lands or in populated areas, mostly for temporary water storage and redistribution. Fluctuating surface levels. Water quality moderate to poor, usually turbid. Fauna: crayfish, tilapia, topminnows, tadpoles.

Effluent Reservoirs. Receiving waters for effluent ditches. Low-quality water, very turbid, often anaerobic. Fauna mainly tolerant invertebrates.

2.2. *Saline or Haline Waters*. Category not further subdivided. Includes single lacustrine ecosystems not classifiable elsewhere. Examples: euhaline Nomilo Pond, Kauai (6.2 ha; maximum depth 20 m) with marine algae, invertebrates, and fishes; poikilohaline Laysan Lagoon, Leeward Archipelago, fluctuating area and depth (maximum area, 70 ha; maximum depth 5 m) with brine flies, *Artemia*, amphipods.

3. PALUSTRINE ECOLOGICAL SYSTEMS.

Lentic waters <2 m deep (usually <1 m). Sometimes in irregular or poorly defined basins.

3.1. Elevated Wetlands. Natural limnetic water bodies located at elevations >100 m. Fauna predominantly native, *no fishes or shrimps*.

3.1a. *Montane Bogs*. Small bodies of acid, open water on elevated 600-2,000 m) flat topography in areas of high persistent rainfall (>500 cm/yr), all islands (Appendix C). Organic and hydromorphic soil substratum. Water clear, cool (<16°), very low in dissolved minerals (conductivity <30 mhos) and yellow to brownish with humic solutes (pH <5.5). Bordered by acidophilic flora (mosses, lichens, dwarf shrubs). Fauna low in abundance and diversity and consists primarily of insects (Odonata, Coleoptera, Diptera).

3.1b. *Ponds and Marshes*. Perennial to seasonally intermittent wetlands in upland areas (100-1,200 m) of moderate to high rainfall, better drained than boglands (Appendix C). Water clear, sometimes yellowish, low to moderate dissolved mineral content (conductivity 30-80 µmhos), and circumneutral (pH 5.5-7.5). Emergent aquatic plants (sedges, grasses) often abundant. Fauna similar to but more abundant and diverse than that of bogs.

3.2. Low Wetlands. Altered or artificial shallow ecosystems located coastally or in valley flats. Variable environmental character. Fauna mainly introduced species; emergent flora predominant.

3.2a. *Limnetic Wetlands*. Perennial freshwater marshes and ponds not immediately adjacent to coastline. Variable water quality: salinity <0.5 /°° (conductivity 100-300 mhos), pH 6-7.5. Includes natural basins such as Kawainui Marsh, Oahu, and artificial basins such as taro fields. Sedges, bullrush, or California grass predominates in wild areas; *Colocasia esculenta* in taro fields. Introduced fauna: crayfish, topminnows, tilapia, *Bufo* tadpoles.

3.2b. *Saline Wetlands*. Seasonal or permanent coastal ponds and marshes of variable salinity resulting from intrusion of haline groundwater or inundation from large waves. No definite or periodic surface connection to ocean. Water warm (20-30°), usually mixohaline and poikilohaline (evaporation may cause seasonal ponds to becomes hyperhaline), pH 6.5-8. Flora: blue-green algae, bullrushes, and sedges (low salinity waters), pickleweed (*Batis maritima*) and mangrove. Fauna: euryhaline fishes (tilapia, sailfin molly) and insects (hydrophilid beetles, *Trichocorixa* water boatman), *Ligia* isopods, *Melania* and *Assiminea* snails. Examples include open ponds (Kealia and Kanaha on Maui), salt marshes (Ewa plain, Oahu), man-made waterbird refuge ponds (Pearl Harbor, Oahu), playa "lakes" (Niihau Island).

4. ESTUARINE ECOLOGICAL SYSTEMS.

Mixohaline water in delineable basins with continuous or periodic surface connection to the ocean, allowing entry of euryhaline marine fauna (excludes waters inhabited by stenohaline marine inshore animals such as corals, urchins, etc.). Tidal fluctuation of surface level.

4a. *Natural Estuaries*. Waters in natural basins individually ranging from limnetic to nearly euhaline. Pronounced stratification of halinity, temperature, and usually oxygen concentration. Diverse native euryhaline fauna including: neritid snails (*Theodoxus*); barnacles, paleamonid shrimps, and grapsid and portunid crabs; gobioid, serrate swimming crab, tilapia, topminnows. Two distinct subtypes of estuaries based on freshwater input and relevance to diadromous fauna.

True Estuaries. Drowned river (stream) mouths. Limnetic water from perennial surface runoff. Inland extent determined by measurable tidal fluctuation and topography. Subtype extremes: *vertically stratified* estuaries with freshwater inflow volume low relative to basin volume (Huleia and Kilauea, Kauai); *horizontally stratified* with relatively large freshwater inflow (Hanalei, Kauai). Poikilohalinity in both subtypes results from wide seasonal fluctuations in stream discharge. Important as migratory pathway for larval and juvenile diadromous stream animals. Most occur on Kauai.

Estuarine Limnocrenes. Nearshore basins with subterranean limnetic water sources (springs). Homoiohaline. Biota similar to True Estuaries but lacks transient diadromous (stream) fauna and has submerged vascular plants. Hawaii Island only (eg. Waiakea and Lokoaka Ponds, Hilo).

4b. *Developed Estuaries*. Estuarine systems constructed recently to prehistorically, or highly modified from natural state. Mixohalinity resulting from groundwater seepage or surface runoff. Water quality variable. Native biota similar to that found in Natural Estuaries, but often dominated by exotic plants (mangrove) or animals (tilapia). Includes walled Hawaiian fishponds (Hawaii, Molokai, Oahu), altered stream mouths (Ala Wai Canal), and biologically modified systems (Heeia Mangrove Swamp and Pearl Harbor sites, Oahu).

5. ANCHIALINE ECOLOGICAL SYSTEM.

Mixohaline lentic waters occurring in recent coastal lava fields or elevated fossil reef rock. No surface connection to ocean but with tidal fluctuations. Unique faunal and algal communities. Ecosystem not subdivided.

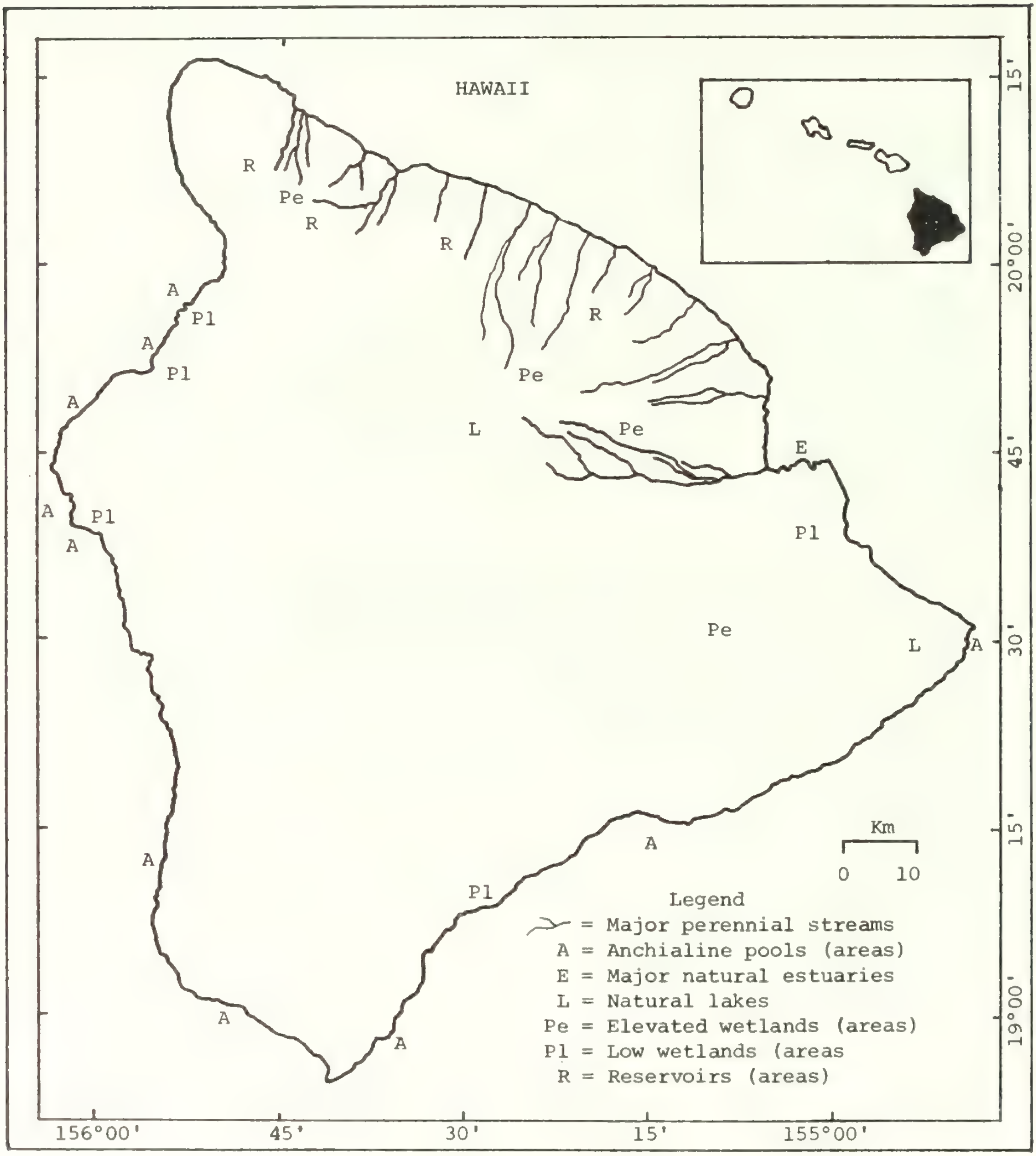
Anchialine Pools. Mostly small, irregular water exposures in barren lava, with or without sediments. Surface level is inland extension of marine water table. Mixohaline water results from dilution of intruding ocean water with seaward-percolating limnetic groundwater. Homoiohaline, but sharp, stable, vertical, salinity stratification is evident in deep pools. Salinity of surface water usually 1-10 °/°° but occasionally approaches euhaline levels. Depth varies with tide; some very shallow pools appear only at high tide. Water usually clear, circumneutral, temperature 22-30°.

Biota distinctive, some faunal species (shrimps) not found elsewhere. Flora: filamentous chlorophytes; mat and crust communities dominated by cyanophytes (*Lyngbya*, *Scytonema*); epilithic rhodophytes (*Hildenbrandtia*); widgeongrass (*Ruppia maritima*) where soft sediments occur. Fauna predominantly shrimps (10 spp.), amphipods and snails (3 spp.); fishes absent or rare. Most characteristic is a small (1 cm) red atyid shrimp, *Halocaridina rubra*; most unusual are sightless hippolytid and procaridid shrimps (only in water >10 °/°°). Introduction of fishes degrades or eliminates crustacean community, changing ecosystem to Haline Low Wetland (type 3.2b).

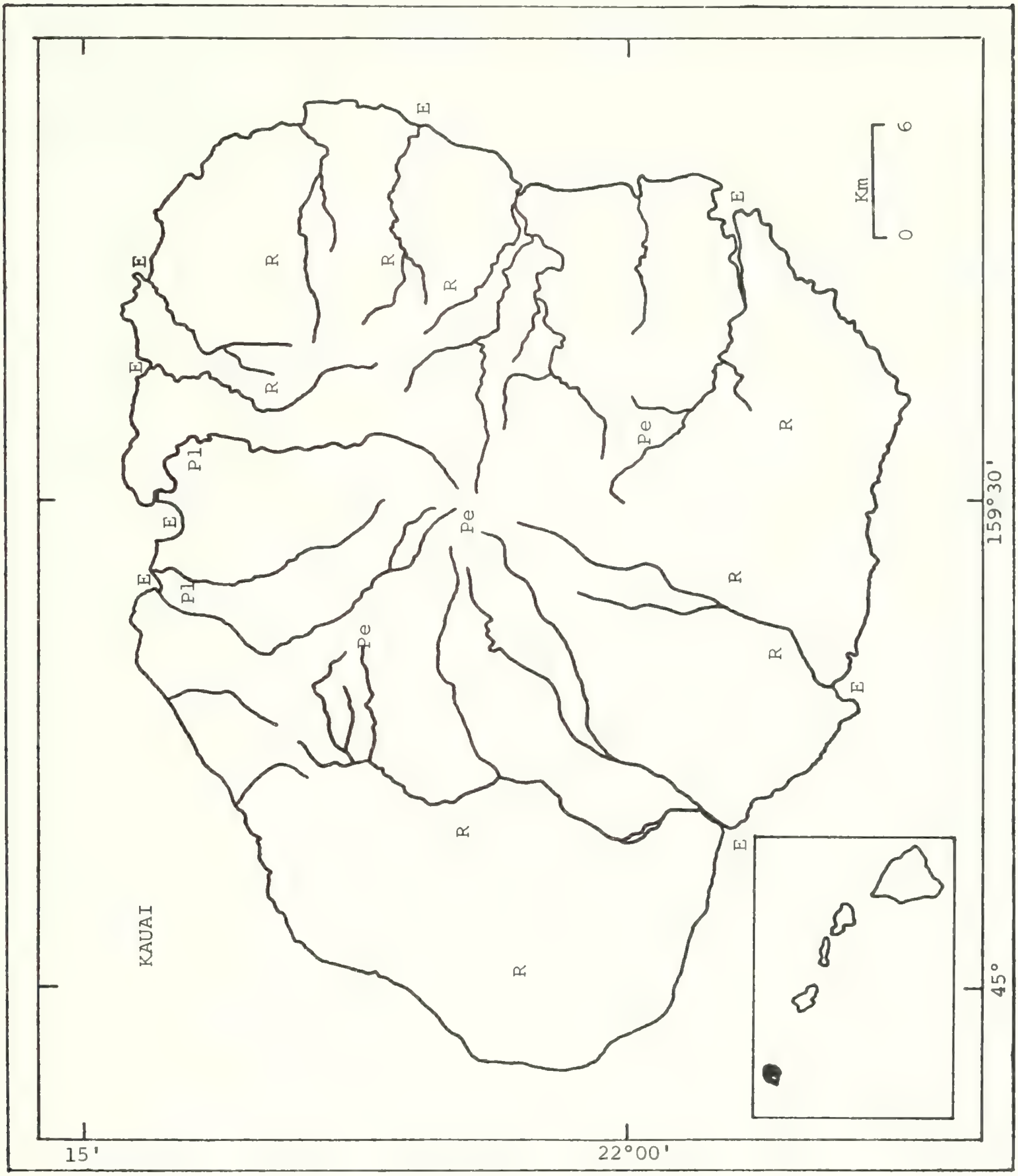
Anchialine pools occur singly and in groups (areas) with subterranean interconnections. Mostly on post-Pleistocene lavas of Hawaii and East Maui Islands (Appendix C). Unusual examples: Waianapanapa Caves, Maui (lava tube); L. Kauhako, Molokai (volcanic vent); Popoia Islet, Oahu (sinkhole in fossil reef).

GENERAL LOCATIONS OF PROMINENT INLAND WATER ECOSYSTEMS

MAP 1, ISLAND OF HAWAII



MAP 2, ISLAND OF KAUAI



Legend

~ = Major perennial streams

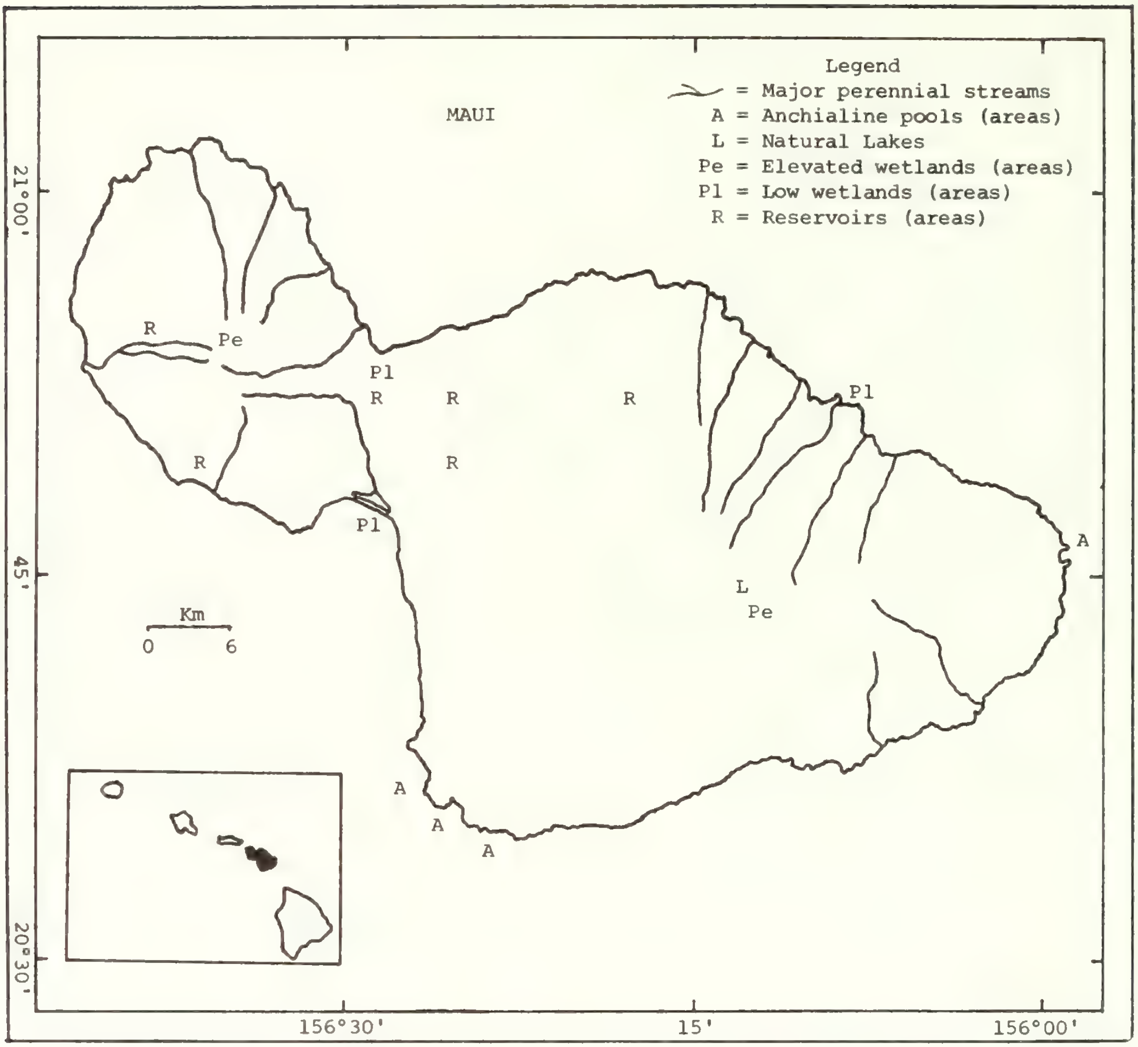
E = Major natural estuaries

Pe = Elevated wetlands (areas)

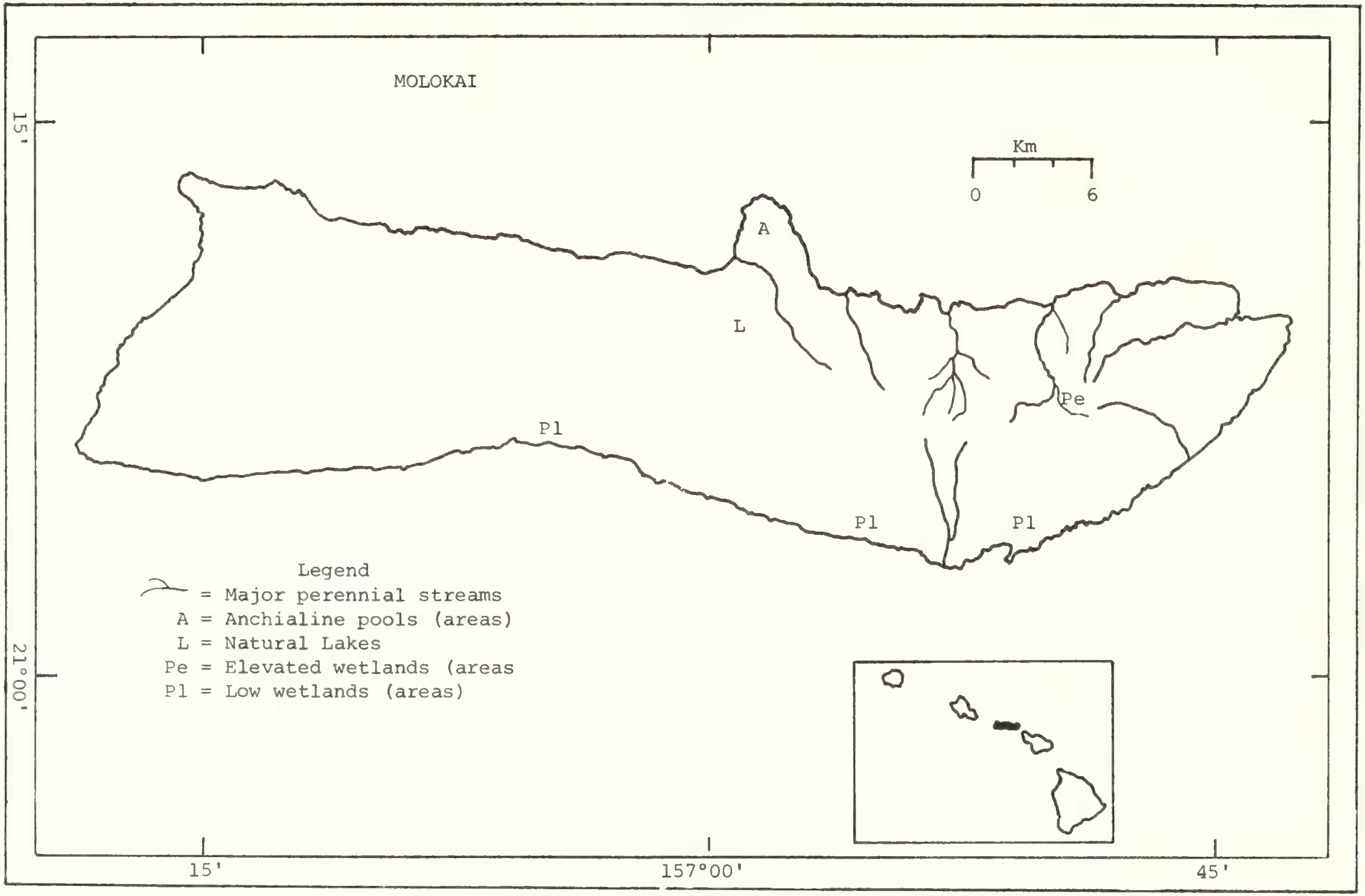
Pl = Low wetlands (areas)

R = Reservoirs (areas)

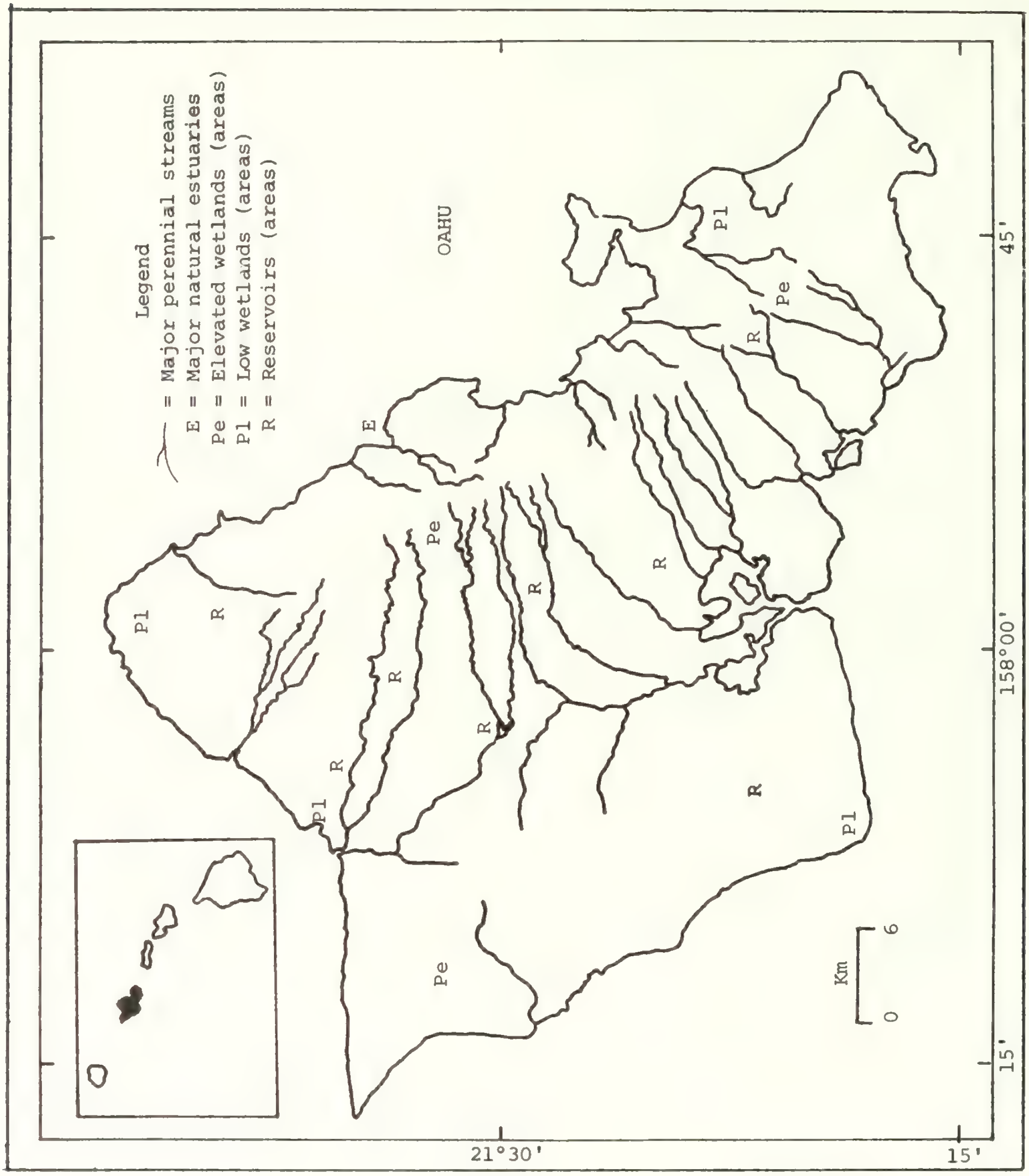
MAP 3, ISLAND OF MAUI


MAUI
Legend
= Major perennial streams
A = Anchialine pools (areas)
L = Natural Lakes
Pe = Elevated wetlands (areas)
Pl = Low wetlands (areas)
R = Reservoirs (areas)
21°00'
45'
20°30'
156°30'
15'
156°00'
Km
0
6
R
Pe
Pl
R
R
R
R
R
Pl
Pl
A
L
Pe
A
A
A

MAP 4, ISLAND OF MOLOKAI


MOLOKAI
Km
0
6
A
L
Pe
Pl
Pl
Pl
Legend
= Major perennial streams
A = Anchialine pools (areas)
L = Natural Lakes
Pe = Elevated wetlands (areas
Pl = Low wetlands (areas)
15'
21°00'
15'
157°00'
45'

MAP 5, ISLAND OF OAHU


Legend
= Major perennial streams
E = Major natural estuaries
Pe = Elevated wetlands (areas)
Pl = Low wetlands (areas)
R = Reservoirs (areas)
OAHU
E
Pe
Pe
Pe
Pe
Pl
Pl
Pl
Pl
R
R
R
R
R
R
R
R
Km
0
6
45'
158°00'
15'
21°30'
15'

A NEW MAP OF THE ECOSYSTEM REGIONS OF THE UNITED STATES

Robert G. Bailey
USDA Forest Service
324 - 25th Street
Ogden, Utah 84401

Abstract: A new map of ecosystem regions of the United States has just been published by the U.S. Forest Service (Bailey, 1976). It was prepared in cooperation with the U.S. Fish and Wildlife Service as part of their national inventory of wetlands program. The explanatory text which accompanies the map is reproduced here.

INTRODUCTION

To manage land as heterogeneous as that land managers deal with they must be able to classify its capability and availability to produce different goods and services. To manage forest, range, and related land on a national, regional, and local scale, requires a classification system that is objective, that covers the whole country, and that is hierarchical in nature. To be objective, the system should be based on observed properties. The same method of classifying land in California should be used in all States. The hierarchical system should allow both broad levels of generalization and highly specific levels, to permit aggregation of data at different levels to meet decisionmaking needs at regional, State, and national levels.

The classification should be developed from existing knowledge. In some instances, it may not be possible initially to characterize lower levels of the hierarchy because of lack of on-the-ground knowledge. Where this is the case, management planning must be based upon existing knowledge at higher levels--even though lack of knowledge at the lower levels may restrict the accuracy of management planning in local areas. The lower classification levels can be defined when research and management gain additional knowledge and experience.

The classification should reflect spatial patterns as well as properties because land (an ecosystem) is a complex of surface attributes. A manager cannot fully predict how a piece of land will behave, in terms of local controls or single factors acting in isolation, but the response is in part determined by relationships with adjoining areas. There is thus intrinsic advantage in assessing land in terms of interacting units at various scales of grouping. The process of grouping objects on the basis of spatial relationships, rather than solely on similarity of taxonomic properties, is called regionalization.

PURPOSE

There are several kinds of regions depending upon objective or purpose. Just as a region based on agriculture is an agricultural region, one based on ecosystems is an ecosystem region or ecoregion.

To date, most work based on the ecosystem concept of resource management is at a detailed level. There are at least two reasons why a regional view of the ecosystem is needed: (1) to permit detailed data to be aggregated into more generalized units for decisionmaking at higher levels, and (2) to provide an integrating frame of reference needed to fully interpret the more detailed information.

This ecoregion map was developed to meet these needs. Maps based on classification of climatic types, vegetation associations, and soil groups have been widely used, but no comparable broad-scale synthesis of these maps has been commonly accepted. The map is an attempt to fill that gap.

Other broad-scale classifications have tended toward systems that are either biotic or abiotic, having as criteria such factors as landform. In trying to use these classifications, it is apparent that they are inadequate because they are not truly holistic, as ecosystem classification requires.

The ecoregion map reconciles the biotic and abiotic classifications into a single geographical classification that is relatively objective. The map scheme is based on a major division of all lands into lowlands and highlands. Within the classification, bioclimatic criteria are used to determine the upper rungs of the hierarchy, and geologic and geomorphic criteria are taken into account mainly at the lower levels; the map shows only the upper levels.

This ecoregion map of the United States is not intended to be a final classification, but is intended to elicit comments from users on format, style, and overall adequacy as a planning aid and educational device. Such comments will be reviewed and incorporated into the design of future versions.

PRINCIPLES OF ECOSYSTEM REGIONALIZATION

Each ecoregion covers a continuous geographical area and is characterized by the occurrence of one or more important ecological associations that differ, at least in proportional area covered, from the associations of adjacent regions. In general, ecoregions are characterized also by distinctive flora, fauna, climate, landform, soil, vegetation, and ecological climax. Within such a region, ecological relationships between plant species, soil, and climate are essentially similar, and similar management treatments give comparable results. Thus, the regions are also considered biological productivity divisions with specific potentials.

The term "ecoregion" was proposed by Crowley (1967). Other conceptually similar terms include "physiographic region," "landscape," "natural region," "biophysical unit" (Lacate 1969), "biogeoclimatic zone" (Krajina 1965), "land system" (Wertz and Arnold 1972), "site region" (Hills 1960), and "biotic province" (Dice 1943). Ecoregion seems preferable since it most closely parallels ecosystem. As used in this manuscript, the ecoregion term designates biogeographical units of any size or rank.

The classification scheme used on the ecoregion map is an adaptation derived mostly from Crowley (1967) and has four levels of generalization (Table 1).

Table 1. A Hierarchy for Ecosystems[a]

[Adapted from Crowley (1967) and Wertz and Arnold (1972)]

	Name	Defined as including:
1.	Domain	Subcontinental area of related climates
2.	Division	Single regional climate at the level of Köppen's types (Trewartha 1943)
3.	Province	Broad vegetation region with the same type or types of zonal soils
4.	Section	Climatic climax at the level of Küchler's potential vegetation types (1964)
5.	District	Part of a section having uniform landforms at the level of Hammond's land-surface form regions (1964)
6.	Landtype association	Group of closely related types with recurring pattern of landforms, lithology, soil, and vegetative series
7.	Landtype	Group of neighboring phases with similar soil series or families with similar plant communities at the level of Daubenmire's habitat types (1968)
8.	Landtype phase	Group of neighboring sites belonging to the same soil series with closely related habitat types
9.	Site	Single soil type or phase and single habitat type or phase

[a] This table is not intended to define the levels precisely, but merely to indicate the general character of the classification. Regional ecosystems or ecoregions are designated at levels 1 - 5.

A domain is a subcontinental area of broad climatic similarity, such as lands having the dry (B) climates of Köppen (Trewartha 1943) or Thornthwaite (1931).

A division is a subdivision of a domain determined by isolating areas of differing vegetation and regional climates, generally at the level of the basic climatic types of Köppen (Trewartha 1943). Usually, the zonal soils are related.

A province is a subdivision that corresponds to a broad vegetative region having a uniform regional climate and the same type or types of zonal soils. For example, the Boreal Forest Province is the ecoregion characterized by the subarctic continental-boreal coniferous forest-podzol ecosystem. Generally, each province is characterized by a single climax association, but two or more climaxes may be represented within a single province. This often happens on mountains where each altitudinal zone may have a different climax.

Mountain regions represent special problems. The middle and upper slopes of mountain regions do not have the same climate as the adjacent lowlands, but instead have the same climatic regime as those lowlands. From the climatic regime of a mountain area, one may infer (1) what the lower altitudinal zones will be and (2) the seasonal pattern of precipitation and temperature in all zones. For example, in a mountain region having a semiarid steppe regime, the steppe zone will occupy the adjacent lowlands and perhaps the lower sunny slopes, then further up the mountain there will be a subhumid prairie or parkland zone, and still higher the montane zone, and so on. By contrast, in a mountain region having a humid climatic regime such as the warm-summer continental, the valley bottoms will be humid and the montane zone will be the lowest zone present. A mountain range in a Mediterranean climatic regime will have a maximum of precipitation in winter in all zones, just as does the adjacent windward lowland. For the purposes of the ecosystem classification, highland ecoregions such as mountains, plateaus, and high-elevation plains (altiplano), in which a high degree of altitudinal zonation occurs, are considered separate provinces. They are classified according to the climatic regime of the lowlands in which they occur.

A section is a subdivision of a province and is based on local climatic variation. The section is characterized by a single climax association and reflects climatic nuances within the broad regional climate. Variation in potential vegetation as mapped by Küchler (1964) is used as the principal indicator of a section.

No attempt was made to identify ecosystems below the level of section on the map. A tentative hierarchy defining levels below section is presented in Table 1.

The concept of "ecoregion" differs from that of "biome" (Shelford 1963), because the area of a biome is coincident with the area of its climax types. Every area having the same climax, however far from the main area of the climax, belongs to the same biome. An ecoregion, on the other hand, is always continuous (except on marine islands). Ecologic communities having characteristics similar to those of a particular ecoregion may exist far beyond its boundaries and thus belong to a different ecoregion.

Each ecoregion comprises both the climax communities and all the successional stages within its geographical area and so includes the freshwater communities. However, the ecoregion does not include marine communities that may lie adjacent to its shores.

The boundaries between adjacent ecoregions are usually difficult to locate precisely. Frequently one ecoregion merges gradually into another and a line separating the two must be drawn arbitrarily. A convenient way of roughly locating the boundary between two adjacent ecoregions is to draw the line where the dominant associations of the two regions cover approximately equal areas.

As stated, an ecoregion may best be thought of as a geographical area over which the environmental complex, produced by climate, topography, and soil, is sufficiently uniform to permit development of characteristic types of ecologic associations. Some ecologic communities are able to modify the natural undeveloped habitat and, to a certain extent, manufacture their own environment. Through ecologic succession, these communities tend to spread from their place of origin to adjacent areas. Accordingly, an ecoregion may also be thought of as a center of ecologic dispersal.

The area covered by a particular ecoregion varies from time to time, not only because of the production of new habitats through ecologic succession, but also because of slow but more or less permanent climatic changes. Any major change in topography will alter the local climate. Other climatic variations of a worldwide nature are believed to be continually in progress. Climatic changes generally affect the geographic distribution of the ecologic units concerned. The ecoregions themselves are slowly evolving and, occasionally, a new one may apear or an old one become extinct. Consequently, regional boundaries are not stationary. Instead, slowly but constantly they are changing their position.

The classification of ecoregions should properly be based upon the distinctness and distribution of various ecologic associations. Unfortunately, available data on the associations of the United States that include both plants and animals are inadequate for this purpose. Actually, the classification of ecoregions presented here is based to a large extent on macroclimate as expressed by potential vegetation. Animals are dependent directly or indirectly upon plants for food and often for shelter and breeding places. Even where plants do not control the distribution of animals, they often indicate the characters of climate and soil upon which animals are dependent. Accordingly, for the present, vegetation offers the most satisfactory basis for distinguishing the major ecologic communities of the country.

The geographic distribution of the ecoregions described here is correlated in varying degrees with climatic types, physiographic provinces, agricultural regions (Atwood 1940), and soils (Soil Survey Staff 1975). This correlation is not surprising when we consider that climate, physiography, and soil all affect one another, and that the distribution of plants and animals is dependent upon all these environmental factors.

The names assigned to each region retain the names of the most obvious vegetative indicator, such as mixed forest, broadleaf forest, or desert. As a rule, designations of the geographic situation are added (i.e., Eastern Deciduous Forest or California Grassland). On the map, color tints designate types of ecoregions by climatic zones. Highlands are shown by line pattern over the color corresponding to the lowland zone. One or two basic colors have been selected for each ecoregion domain and divisions within domains are shown in tones of the basic color. For example, green tones are used for the humid temperate domain and orange-red for the dry domain. Darker tones are used for humid, oceanic types, and lighter tones for drier, interior types.

DEVELOPMENT OF THE MAP

In developing the ecoregion map, a large number of geographical and ecological works were consulted. The selected references do not cover all sources from which the map was drawn. The Selected References supplement the information presented here, and lack of space prevents the inclusion of many important papers. A number of persons intimately acquainted with different regions have given valuable advice and criticism.

Particularly useful in delimiting climatic regions were the climatic map of the world, modified from the Koppen classification (Trewartha 1943) at a scale of 1:75,000,000, and the climatic map of North America (Thornthwaite 1931) at a scale of 1:20,000,000. These latter two maps were used with some modification to identify domains and divisions. The regions at the level of section were delimited from a number of sources, especially from an examination of Kuchler's (1964) map of "Potential Natural Vegetation" at a scale of 1: 3,168,000. Kuchler's map was generalized and modified to delineate provinces and sections.

APPLICATIONS AND REFINEMENTS

Any biogeographic classification must be partially arbitrary and many compromises must be made if the diverse ecologic relationships of the country are to be brought together into a single system. Biogeographers and ecologists have not agreed on the classification system best suited to the needs of all who may use organized information about the distribution of ecosystems. It may be impossible to devise a system equally well suited to the diverse needs of users in widely separated fields, but agreement, at least on major units of ecologic classification, is desirable.

This map of the ecoregions of the United States is offered as an experiment in classifying the major ecologic divisions of the country. By regionalizing, the variation in the environment is reduced to manageable proportions. In addition, regionalization provides a framework for organizing our knowledge of ecosystems and for extrapolation of knowledge from one area for application in the management of another one. Such a classification and map can serve as a valuable reference work for land use and resources assessment, for planning on a nationwide scale, and they are especially important in coordinating more detailed work. Further, the map and classification can contribute substantially to tying together regional legends and standardizing symbols, nomenclature, and ways of making detailed ecosystem maps consistent with regional and national maps.

An effort has been made throughout to have categories reflect the most significant aspects of ecosystems consistent with scale. However, the author is acutely aware that this is not always possible. Classification is severely hampered by lack of data or inconsistencies of data available in many areas. Of necessity, arbitrary decisions sometimes have been made. Additional work may suggest better terminology or more accurate delimitation; however, considering the level of generalization of the map, it is doubtful that such delimitation would alter the pattern appreciably. It is hoped that future work will test and revise the classification and refine it at lower levels.

The author is preparing (1978) a separate text more fully describing the methodology and the units shown on this map.

ACKNOWLEDGMENTS

While accepting full responsibility for the map, particularly for any errors or deficiencies, I wish to acknowledge the work of Professor John M. Crowley of the University of Montana, who advanced the concept of ecoregions for North America, upon which this more detailed work is based. Professor Edwin H. Hammond, Mr. Kermit N. Larson, Dr. Charles T. Cushwa, and Dr. Ed F. Schlatterer have lent encouragement and helpful suggestions since the map was begun. Mr. John H. Wikstrom and Dr. Robert D. Pfister have also given counsel, and their advice has been most appreciated. Finally, a special note of thanks is extended to Mr. William A. Wertz and Mr. John F. Arnold who originally proposed this project.

SELECTED REFERENCES

Atwood, W. W. 1940. The Physiographic Provinces of North America. Boston, Ginn, and Co. 536 pp.

Bailey, R. G. 1976. Ecoregions of the United States. (Map.) U.S. Department of Agriculture, Forest Service, Intermountain Region, Ogden, Utah. Scale 1:7,500,000.

Burger, D. 1976. The concept of ecosystem region in forest site classification. Proc. XVI IUFRO World Congress, Oslo, Norway, 1976. 6 pp.

Corliss, J. C. and R. D. Pfister. 1973. ECOCLASS - A Method for Classifying Ecosystems. USDA Forest Service, Missoula, Montana. 52 pp.

Crowley, J. M. 1967. Biogeography. Canadian Geog. II:312-326.

Daubenmire, R. 1968. Plant Communities: A Textbook of Plant Synecology. New York, Harper and Row. 300 pp.

Dice, L. R. 1943. The Biotic Provinces of North America. Univ. Michigan Press. Ann Arbor. 77 pp.

Hammond, E. H. 1964. Classes of Land-Surface Form in the Forty Eight States, U.S.A. Assoc. Geog. 54, Map Suppl. 4, scale 1:5,000,000.

Hills, G. A. 1960. Regional site research. For. Chron. 36:401-423.

Krajina, V. J. 1965. Biogeoclimatic zones and classification of British Columbia. Univ. Brit. Columbia, Vancouver. In V. J. Krajina (ed.), Ecology of Western North America. pp. 1-17.

Küchler, A. W. 1964. Potential Natural Vegetation of the Conterminous United States (map and manual). Am. Geog. Soc. Spec. Publ. 36, 116 pp., map scale 1:3,168,000.

Lacate, D. S. 1969. Guidelines for Bio-physical Land Classification--for Classification of Forest Lands and Associated Wildlands. Can. For. Serv. Publ. 1,264, Ottawa. 61 pp.

Meurisse, R. T., J. T. Schmautz, and C. T. Cushwa. 1974. Criteria for Establishing and Describing Ecological Units on National Forest System Lands. USDA Forest Service, Wash., D.C. 14 pp.

Oosting, H. J. 1956. The Study of Plant Communities. W. H. Freeman & Co., San Francisco. 440 pp.

Shelford, V. E. 1963. The Ecology of North America. Univ. Illinois Press, Urbana. 610 pp.

Soil Survey Staff. 1975. Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys. U.S. Dept. Agric. Soil Conserv. Serv. Agric. Handb. 436. Washington, D.C.

Thornthwaite, C. W. 1931. The climates of North America according to a new classification. Geog. Rev. 21:633-655.

Trewartha, G. T. 1943. An Introduction to Weather and Climate. McGraw-Hill Book Co., New York, 2nd ed. pp. ___.

Wertz, W. A. and J. F. Arnold. 1972. Land Systems Inventory. USDA For. Serv. Intermountain Region, Ogden, Utah. 12 pp.

A PHYSIOGRAPHIC—PHOTOMORPHIC TECHNIQUE OF HABITAT CLASSIFICATION

E.J. Hodgkins and T.K. Cannon
Department of Forestry
Auburn University
Auburn, Alabama 36830

Abstract: The author's physiographic--photomorphic technique of habitat classification and mapping evolved from an earlier physiographic technique which was modeled after Hill's "physiographic site" system in Canada. The physiographic technique is based on simple physical ecology, which is a part of the basic training of most professional land managers. The physiographic--photomorphic technique incorporates the use of satellite imagery for adding photomorphic information for the classification work, as well as adding a photographic map base.

This paper explains the classification system used in "Forest Habitat Regions from Satellite Imagery: States of Alabama and Mississippi", Hodgkins et al., (1976). First we discuss general "habitat" and "habitat classification," follow with an explanation of an earlier physiographic system of habitat classification (Hodgkins, 1965), and finally, show how we used satellite imagery in a "physiographic--photomorphic" technique of habitat classification and mapping.

HABITAT AND HABITAT CLASSIFICATION

Hanson Dictionary of Ecology (1962) defines "habitat" as "The sum total of environmental conditions of a specific place that is occupied by an organism, by a population, or a community." The definition implicitly divides the ecosystem into: (1) the resource portion ("organism," "population," "community") which interests human users and consumers, and (2) the remainder of the ecosystem which becomes the environment or "habitat" for the resource portion. The habitat portion includes all the physical, or abiotic, aspects of the ecosystem, plus a variable amount of the biotic aspects, depending on the portion of these that is assigned to the "resource." For the multiple-use manager of forests, the entire biotic community is the resource; therefore habitat is wholly abiotic. A manager of a game population, on the other hand, should include much of the biotic in his concept of habitat.

"Habitat classification" is any abstract system of grouping similar habitats into hierarchical categories. At the lowest or "contact" level, the physical habitat type should be uniform relative to the combined environmental effects of regional climate, topographic situation, and soil-geologic materials. There are two systems of physical habitat classification which are familiar to many. One of these is the National Cooperative Soil Survey, which is based on the science of "soil taxonomy" (USDA Soil Conservation Service 1975) and essentially requires the services of soil scientists for its application. The other system is Hills' (1961) "physiographic site" system, which is based on outright environmental considerations and hopefully might be mastered by any competent field ecologist (Figure 1).

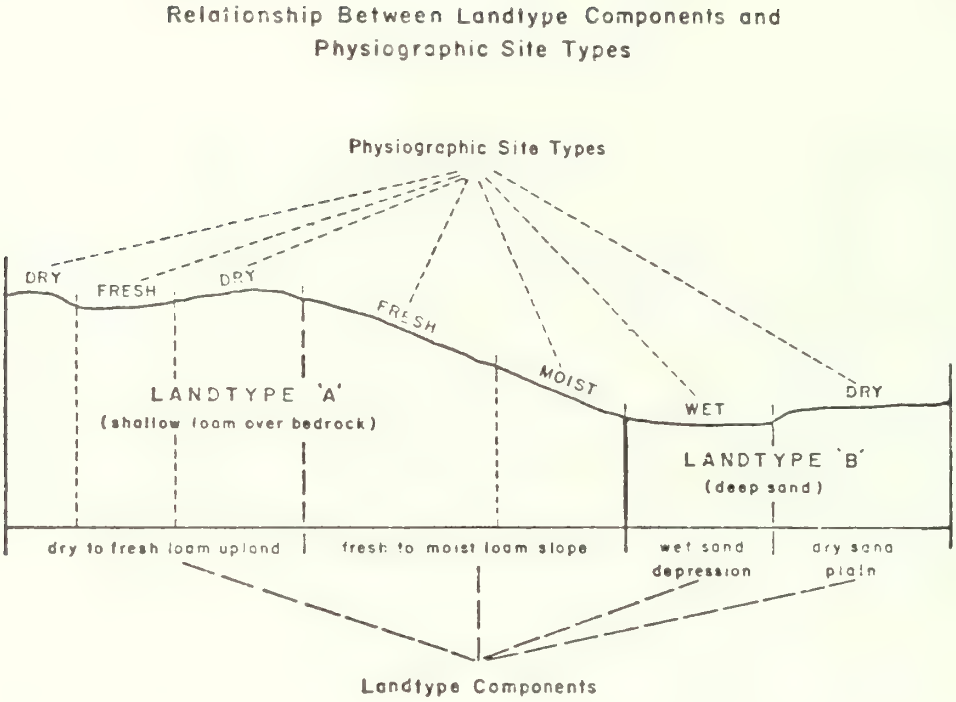


Figure 1. An illustration of Hills' system of physiographic habitat classification.

SOUTHEASTERN PHYSIOGRAPHIC HABITAT CLASSIFICATION

In the 1965 "Southeastern Forest Habitat Regions Based on Physiography" (Hodgkins, 1965), Hills' concepts were followed except that the conventional southeastern provinces (Piedmont, Ridge and Valley, etc.) were used at the highest categorical level. These were presented subdivided into regions on a planimetric base map. The regions were based on differences in geologic or soil material within the province. All regional subdivisions were made in such a manner that ultimate local subdivisions could be uniform with respect to habitat on the basis of topography-soil material combinations. A third unmapped categorical level was presented (Hodgkins, 1965) that subdivided regions on the basis of finer topographic-soil characteristics. For example, the Loamy Soils Region of the Undulating Coastal Plain Province contains typical loamy sand over sandy clay loam, deep sands, shallow sandy loam over clay, poorly drained depressions, and hillside savannas.

In formulating the two levels of classification below province in Hodgkins (1965) the editors and authors relied most heavily on previously published materials in the areas of physiography, geology, and soil taxonomy. The descriptions found were simply "re-expressed" in terms of a simple physical ecology. This procedure was not basically altered in later efforts that utilized the satellite imagery. There was some field checking, in both the earlier and later efforts, but this was necessarily of an extensive nature.

It was felt that the 1965 publication, with its three higher levels of classification, could help the field ecologist place himself in the right "ball park" for lower levels of classification. These lower levels were visualized as being carried out by the field ecologist with respect to the specific goals involved and local environmental variation. For instance, a forester in the Loamy Soils Region who is interested in habitat productivity for longleaf pine (Pinus palustris) could establish lower-level habitat divisions as shown in Table 1. To do this job of local "physiographic habitat classification and evaluation," the forester would need sound fundamental knowledge of local habitat relations, but he would not need to be, or to call upon, a soil-scientist.

PHYSIOGRAPHIC--PHOTOMORPHIC HABITAT CLASSIFICATION

The basic classification was not changed when satellite imagery was introduced into the work (Hodgkins et al., 1976). In effect, a satellite imagery base was substituted for a planimetric map base, and then any new information thus made available was added to information previously available from other sources.

We used black and white ERTS prints of multispectral scanner bands 5 and 7 enlarged to a scale of 1:500,000. These have virtually no distortion, and after control points have been established on them, the prints can be used as maps of acceptable accuracy. Many state-size or smaller maps of surface geology, soil associations, topography, and vegetation that are available at the same scale can be overlaid in transparency form on these prints to aid in the identification of visible photomorphic features. We have found that landforms and land use patterns are most distinct in the band 7 and band 5 imagery, respectively. The former are directly utilizable and the latter indirectly utilizable in our classification system (Figure 2).

Table 1. Example of the Derivation of Local Physiographic Habitat Types from a Habitat Region, Using the Loamy Soils Region, Undulating Coastal Plain Province, from "Southeastern Habitat Regions" (Hodgkins, 1965)

TYPE[a] (Hills' "Landtype")	SUBTYPE[b] (Hills "Physiographic Site Type")	LONGLEAF SITE INDEX
Typical (loamy sand over sandy clay loam in subsoil)	Flat Upland	80 - 85
	Ridge	65 - 70
	Slope 2-7%	75 - 80
	Slope 8%+	70 - 75
	Footslope	80 - 85
Deep sands	Slope 1 - 3%	75 - 90
	Slope 4 - 7%	65 - 75
	Slope 8%+	55 - 65
	Footslope	80 - 90
Clay subsoils (sandy loam topsoil)	Footslope	75 - 85
Savannas	- - - -	N/A
Ponds and small stream bottoms	0 - 15.2 cm not mottled	80 - 85
	0 - 15.2 cm mottled	75 - 80
	0 - 15.2 cm mucky	N/A

[a] Lowest classification category in the text.

[b] Subclassification for field variations.

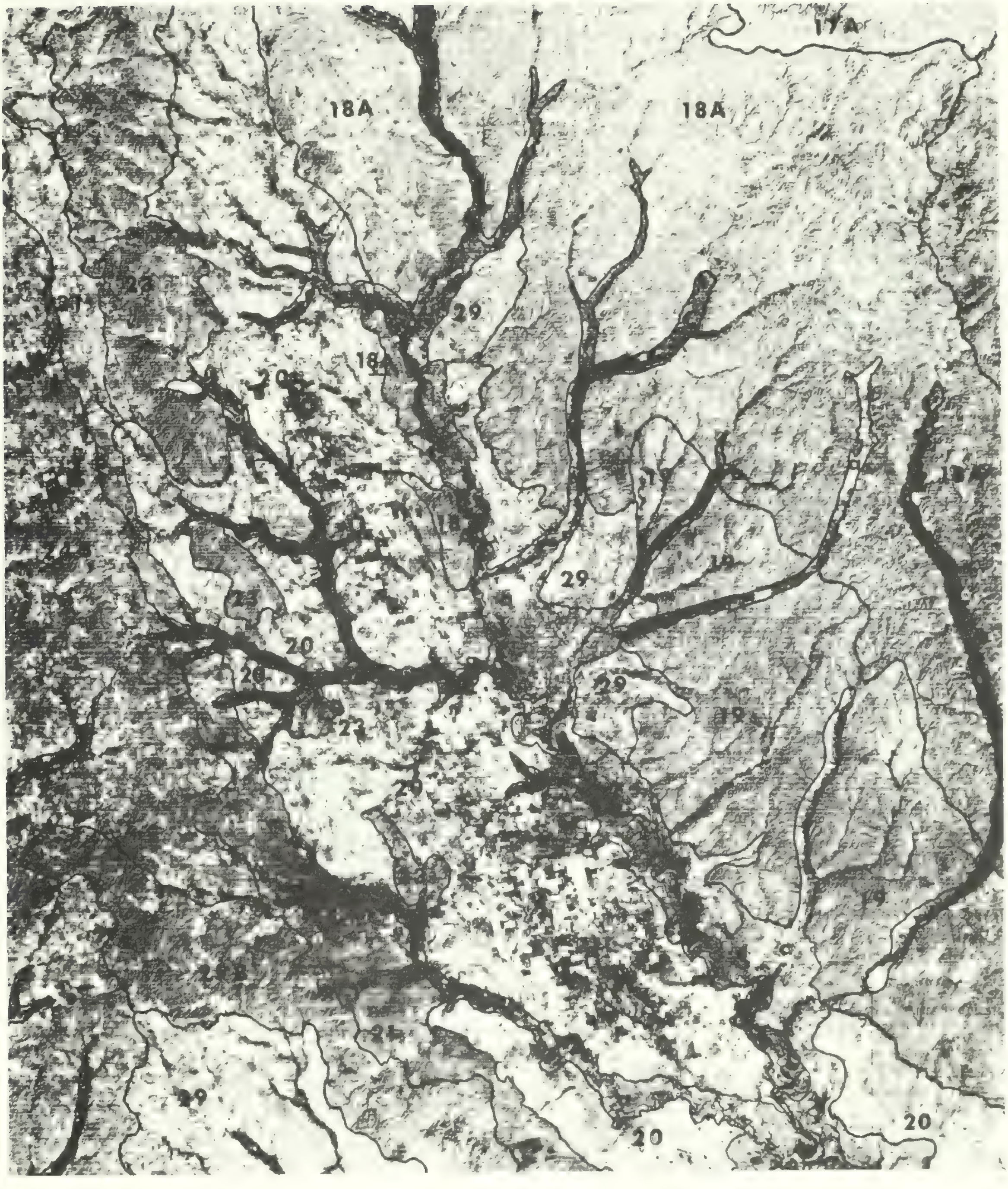


Figure 2. ERTS 1:1 million scale print (band 7) with habitat regions delineated. Note reliance on landform and land-use patterns. Sample type names (Types 19, 20, 21, and 29 respectively) are Clay Hills, Blackbelt, Interior Flatwoods, and Old Terrace Regions of the Hilly Coastal Plain Province, Location: both sides of Mississippi-Alabama border.

Good satellite imagery was found to be a superior source of the following kinds of information: (1) planimetric detail of larger and more pronounced landform features--as judged from shade, texture, and drainage pattern differences in band 7 prints; (2) degree and pattern of land-clearing in band 5 prints; and (3) location of hitherto unrecognized and unmapped physiographic regions, such as the "Jackson Hills" in Mississippi. We consider satellite imagery superior to high-level aerial photographs because of the complete coverage available and because it provides undistorted synoptic views of large physiographic units.

Important physiographic changes were not always obvious and sometimes were not apparent on the satellite imagery. Prolonged study, however, often revealed much that was not apparent in early examinations. On the other hand, important physiographic changes were occasionally not attended by any discernible changes in shade, texture, drainage patterns, or land use on the imagery. An example of this is the lack of any apparent delineation of the Carolina Slate Region within the Piedmont of Georgia.

After delineating provinces, habitat regions, and subregions on the prints for Alabama-Mississippi, this information was transferred to a satellite image mosaic of the two-state area at the reduced scale of 1:1,000,000. Descriptions of the habitat regions that could be accommodated in the limited space on the obverse of the mosaic were written. The following description of the Sandstone Plateau Region is an example.

The Table Plateaus. Sand Mountain and Lookout Mountain. These two plateaus exhibit relatively little geologic dissection. Extensive areas of gently sloping sandstone soils are a dominant feature. These soils, typically sandy loam topsoil over sandy clay loam subsoil, are intensively cultivated where the depth to bedrock is more than about 30 inches (76 cm) (Hartselle, Linker). The shallower soils (Hector, Mountainburg), fairly extensive on Lookout Mountain, are often available for forest growth and perhaps best adapted to Virginia pine (Pinus virginiana). The best soils available for forests are deep silt loams (Albertville, Enders) on valley slopes that are too steep for cultivation. Here, geologic erosion has broken through the sandstone cap allowing the older shale to influence the soils. There are also shallow soils on steep slopes (Hector, Townley), with the bounding escarpments of the plateaus containing shallow Rockland soils (both sandstone and limestone) and deep colluvial soils (Allen) as well.

The Dissected Plateaus. A contiguous area containing the cities of Jasper and Cullman. The land-types and soils are the same as 3A, but the proportion of strongly sloping land is much higher because the original plateau has been much more dissected. Quality of the soils for forests, which is poor to excellent, is a function of depth to bedrock and the proportion of shale to sandstone in the soil-forming rock (as well as the topographic situation). The best soils have developed from deep mountain colluvium accumulated on lower mountain slopes and in small mountain valleys.

When descriptions of this kind were written, much of the information was deduced from county soil survey reports of recent vintage. We plan to write more detailed and expanded descriptions in a separate document.

We reemphasize the following concerning our procedures for physiographic--photomorphic habitat classification. First, the goals remain identical with those of the earlier physiographic habitat work. Second, the published maps and descriptions are for the higher levels of a complete physiographic habitat classification system, as before. And third, the satellite imagery adds accuracy and detail that would not be available without the imagery. The added detail includes new habitat divisions that were unknown without the imagery.

CONCLUDING REMARKS

Although our Alabama--Mississippi map of habitat regions was designed primarily for forest managers, it is perhaps not surprising that other professional groups have been attracted by it. The physiographic--photomorphic classification system as presented is based on sound concepts of environmental ecology, and, seems relatively easy to comprehend and to use. Potential users may be further attracted after they learn the full extent of the contributing information applied in the system.

LITERATURE CITED

Hanson, H.C. 1962. Dictionary of Ecology. Philosophical Lib., Inc., New York, N.Y. 382 pp.

Hills, G.A. 1961. The Ecological Basis for Land Use Planning. Ontario Dept. Lands and For. Res. Branch. Res. Rep. 46, 204 pp.

Hodgkins, E.J. (ed.). 1965. Southeastern Forest Habitat Regions Based on Physiography. Auburn Univ. Agric. Exp. Stn. For. Dept. Ser. 2, 10 pp.

Hodgkins, E.J., T.K. Cannon, and W.F. Miller. 1976. Forest Habitat Regions from Satellite Imagery: States of Alabama and Mississippi. Alabama. Agric. Exp. Stn., and Mississippi Agric. and Forestry Exp. Stn. Southern Coop. Ser. Bull. 210, Map Scale 1:100,000.

USDA Soil Conservation Service. 1975. Soil Taxonomy. Agric. Hand. 436. Washington, D.C. 754 pp.

THE IUCN DIRECTORY OF WETLANDS OF INTERNATIONAL IMPORTANCE

Erik Carp
International Union for Conservation of Nature
and Natural Resources
c/o Station Biologique de la Tour DuValat
Le Sambuc, 13200, Arles, France

Three major projects with the purpose of evaluating the importance of wetlands have been cosponsored by the International Union for the Conservation of Nature and Natural Resources (IUCN). These are:

PROJECT MAR

This project dealt with the conservation and management of temperate marshes, bogs, and other wetlands, and resulted from the International Conference on Wetlands (MAR Conference), held at Saintes-Maries-de-la-Mer, Camargue, France in 1962. It was cosponsored by the International Council for Bird Preservation (ICBP) and the International Waterfowl Research Bureau (IWRB). A list of European and North African Wetlands of International Importance (MAR List) was published in 1965. This list is based mainly on information concerning the importance of wetlands as breeding, migrating, and wintering sites for waterfowl populations.

PROJECT AQUA

The project originated in 1959 and was cosponsored with International Biological Programmes (IBP). It deals with the conservation of aquatic habitats and its aim is to list bodies of water, mainly rivers and lakes, selected for their limnological and hydrobiological qualities. A list of AQUA sites was published in 1969 followed by a second edition in 1971 including about 650 areas in 76 countries. A third revised and extended version may be published in the near future.

PROJECT TELMA

This project is dealing with the conservation of peat-forming formations. It was initiated in 1966 and cosponsored with IBP. A list of temperate peatlands is in preparation.

Realizing that the MAR List was becoming rapidly outdated, only 8 years after its publication, by developments in most countries, IUCN aimed for a new publication which would revise, add to, and widen the information on the list by combining information of the three projects. Initially it was hoped that the data could be published in a loose-leaf form which would describe wetlands worldwide. Information could then be added as data on additional sites became available. However, in view of the considerable costs involved in such a long term project this concept was abandoned in 1976 and preference has been given to a bound publication which will only cover the wetlands of international importance in the Western Palearctic. The manuscript for this publication will be ready in the spring of 1978.

THE OUTLINE OF THE DIRECTORY

Besides introductory pages, including the criteria for the selection of sites and the classification system, the Directory will contain a list and a map for each country plus a few paragraphs sketching the general situation concerning sites of international importance in that country. The list will mention geographical coordinates, size in hectares, and status of protection of the various sites. Unfortunately it will not be possible to describe each individual site in detail, but a number of the most typical sites in a country will be selected for a more detailed description, including data concerning their location, area, altitude, depth, legal status, ownership, characteristics of their ecology, management practices, threats, research and literature references.

DEFINITION OF A WETLAND IN THE SENSE OF THE DIRECTORY

The wetlands under consideration in the Directory correspond to the definition of a wetland given in Article 1 of the Convention of Wetlands of International Importance, especially as Waterfowl Habitat, generally known as the Ramsar Convention and which came into operation on 21 December 1975 (Carp, 1972). "For the purpose of this Convention wetlands are areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters." (Carp 1972:18.)

CRITERIA FOR THE SELECTION OF WETLANDS OF INTERNATIONAL IMPORTANCE SUITABLE FOR APPLICATION ON A WORLDWIDE BASIS

Criteria for evaluating the importance of a site were developed for the projects MAR, AQUA, and TELMA. Szijj (1972) and Atkinson-Willes (1972 and 1976) have developed and tested criteria for the selection of sites based on simultaneous waterfowl counts carried out since 1967 in mid-January in Europe, North Africa, and Southwest Asia. There are of course other factors which may give a wetland international status. During the International Conference on Wetlands and Waterfowl at Heiligenhafen, Federal Republic of Germany, December 1974, the Committee on Criteria for Identifying Wetlands of International Importance, after studying the criteria used by the various projects, drew up a new set which covers the most evident factors determining the international importance of a wetland. These criteria, recommended by the Conference, fall into four distinct groups:

CRITERIA PERTAINING TO A WETLAND'S IMPORTANCE TO POPULATIONS AND SPECIES

A wetland should be considered internationally important if it:

a) regularly supports 1 percent (being at least 100 individuals) of the flyway or biogeographical population of one species of waterfowl,

b) regularly supports either 10,000 ducks, geese, and swans, or 10,000 coots, or 20,000 waders,

c) supports an appreciable number of an endangered species of plant or animal,

d) is of special value for maintaining genetic and ecological diversity because of the quality and peculiarities of its flora and fauna, and

e) plays a major role in its region as the habitat of plants and of aquatic and other animals of scientific or economic importance.

CRITERIA CONCERNED WITH THE SELECTION OF REPRESENTATIVE OR UNIQUE WETLANDS

A wetland should be considered internationally important if it:

a) is a representative example of a wetland community characteristic of its biogeographical region,

b) exemplifies a critical stage or extreme in biological or hydromorphological processes, and

c) is an integral part of a peculiar physical feature.

CRITERIA CONCERNED WITH THE RESEARCH, EDUCATIONAL, OR RECREATIONAL VALUES OF WETLANDS

A wetland should be considered internationally important if it:

a) is outstandingly important, well-situated, and well-equipped for scientific research and for education,

b) is well studied and documented over many years and with a continuing program of research of high value, regularly published and contributed to by the scientific community, and

c) offers special opportunities for promoting public understanding and appreciation of wetlands, open to people from several countries.

CRITERIA CONCERNED WITH THE PRACTICALITY OF CONSERVATION AND MANAGEMENT

Notwithstanding its fitness to be considered as internationally important on one of the criteria set out under 1, 2, and 3 above a wetland should only be designated for inclusion in the list of the Ramsar Convention if it:

a) is physically and administratively capable of being effectively conserved and managed,

b) is free from the threat of a major impact of external pollution, hydrological interference, and land use or industrial practices, and

c) a wetland of national value only may, nevertheless, be considered of international importance if it forms a complex with another adjacent wetland of similar value across an international border.

CLASSIFICATION OF WETLAND TYPES

The classification system adopted for the Directory is based on the main natural complexes distinguished by Isakov (1966) and further developed and tested by Eber (1969) for waterfowl habitat in the Federal Republic of Germany. No attempt has been made to distinguish the types of habitat which comprise the next level of classification in Isakov's scheme, nor to refer to the vegetation. The scheme has been kept simple. The wetland types have been numbered from 1 to 25.

COASTAL AREAS

Open sea shallow waters

1. Intertidal zone of open sea, shallow waters.
2. Permanent shallow waters in open sea.

Sea bays and straits

3. Shallow sea waters, bottom uncovered at low tide.
4. Deep sea bays (fjords).
5. Shallow sea bays (always covered).
6. Fresh and brackish water bays.
7. Lagoons, both salt and fresh (including artificial lagoons).

Mouths of rivers

8. Tidal estuaries.
9. Deltas.

Coasts

10. Small islets.
11. Continental and large island coasts (including coastal marshes, dunes, rocky, or sandy shores).

RIVER VALLEYS

Rivers and floodplains

12. Lowland rivers (meandering), (including floodplains and interior or dry deltas).
13. Mountain rivers.
14. Brooks.

Storage reservoirs

15. Storages with relatively stable level of water.
16. Storages with great changes of water level.

OTHER AREAS

Lakes

17. Salt lakes (including periodical intermittently fresh lakes).
18. Fresh eutrophic lakes (including periodical intermittent lakes never salty).
19. Fresh oligotrophic lakes.
20. Fresh dystrophic lakes.

Mires

21. Fen and transitional mires.
22. Peat-bogs.

Temporary waters

23. Temporary waters from snowmelt or rainfall (wherever situated).

Artificial ponds

24. Ponds (including fish, mill, and farm ponds) and small reservoirs.
25. Irrigation and drainage systems (including rice fields, drainage ditches, and pits with water).

PURPOSE OF THE DIRECTORY

The Directory is meant to identify and obtain recognition of wetlands of international importance. The list should enable authorities in charge of nature conservation in the various countries to select sites for the purpose of the Convention on Wetlands of International Importance especially as waterfowl habitat. This convention was established on 21 December 1975 and at present the following countries have become a partner to this agreement: Australia, Bulgaria, Finland, Federal Republic of Germany, Greece, Italy, Iran, New Zealand, Norway, Pakistan, Republic of South Africa, Sweden, Switzerland, United Kingdom and the USSR. Other countries have signed this document but have not ratified yet. These are: Belgium, Ireland, the Netherlands, and Portugal. A number of other countries are expected to sign in the near future. It is also hoped that the U.S.A. will become a partner to this Convention.[1]

In compiling the material for the Directory a certain amount of difficulties are met, especially by the fact that the cooperation of scientists in the various countries is on a voluntary basis. Sometimes delays in receiving data are extremely long and often the coordinator has to carry out a great amount of literature research himself to collect the information. Many wetland areas in the Western Palearctic, especially in parts of the Middle East and in North Africa, have not been researched or only insufficiently studied. Most European countries have only recently started surveying and listing their natural areas for conservation purposes. An exception is Great Britain where intensive and systematic surveying started by the Nature Conservancy in 1947. Review of key areas took place in 1955 and 1965.

---

[1] Four other countries have signed the Ramsar Convention during the course of 1977: Jordan, Yugoslavia, Senegal, and Denmark.

The British activities for the selection of sites worth being conserved included an intensive survey of coastlands, woodlands, lowland-grasslands, heath and scrub, open waters, peatlands, uplands and artificial ecosystems, considering their value for conservation and maintenance, survey and research, experiments, education, and leisure. The criteria for site assessment and selection comprised:

1. extent of the area,
2. diversity,
3. naturalness,
4. rarity,
5. fragility,
6. representativeness,
7. recorded history,
8. position in an ecological/geographical unit, and
9. potential value.

The classification scheme in use for the wetland areas was the following:

Coastal areas

a) Flats
b) Saltmarshes
c) Dunes
d) Lagoons and fens
e) Vegetated shingle
f) Rocky shore and cliff habitats
g) Submaritime grassland and heath
h) Paramaritime habitats

Open waters

a) Standing waters

   1. Dystrophic
   2. Oligotrophic
   3. Mesotrophic
   4. Eutrophic
   5. Calcareous
   6. Brackish
   7. Temporary

b) Running waters

   1. Upland
   2. Oligotrophic
   3. Eutrophic
   4. Calcareous

5. Sluggish
6. Subterranean

In order to evaluate the sites a six point grading system was adopted.

Grade 1. - Sites of international or national importance and meriting the status of a National Nature Reserve.

Grade 2. - Sites of equivalent or only slightly inferior scientific merit to the Grade 1 sites.

Grade 3. - Sites of high regional importance rated as high-quality sites of special scientific interest but not of National Nature Reserve standard.

Grade 4. - Sites of lower regional importance, still of special scientific interest for their local value.

Grade 5. - Sites with some conservation value but without notification as a site of special scientific interest.

Grade 6. - Sites of only slight conservation value.

Publication of this ambitious review by the British Nature Conservancy is expected soon (Ratcliffe 1977).

It is hoped that publication of the IUCN Directory of Wetlands of International Importance in the Western Palearctic can take place by the end of 1977 or the beginning of 1978. It would, of course, be desirable to extend the Directory with volumes covering, as was originally planned, wetlands in all parts of the world. However, this will depend on the availability of the necessary funds. A great help would be adaptation of a minimum survey program in each country coordinated on an international basis. This might be discussed in the next Conference on the Conservation of Wetlands and waterfowl to be organized by IWRB, probably in 1978.

LITERATURE CITED

Atkinson-Willes, G.L. 1972. The International Wildfowl censuses as a basis for wetland evaluation and hunting rationalization, pp. 87-110 In E. Carp (ed.), Proceedings of the International Conference on Conservation of Wetlands and waterfowl. Ramsar, Iran, 1971. Intl. Waterfowl Res. Board, Slimbridge (Glos.), England.

Atkinson-Willes, G.L. 1976. The numerical distribution of ducks, swans and coots as a guide in assessing the importance of wetlands. pp. 199-254 In M. Smart (ed.), Proceedings of the International Conference on Conservation of Wetlands and Waterfowl. Heiligenhafen, Fed. Rep. of Germany, 1974. Intl. Waterfowl Res. Board, Slimbridge (Glos.), England.

Carp, E. (ed.). 1972. Proceedings of the International Conference on Conservation of Wetlands and Waterfowl. IWRB, Slimbridge (Glos.), England.

Eber, G. 1969. Zum vorläufigen Schema der Typologie und Klassifikation von Wasservogel Biotopen. Ornithologische Mitteilungen 21(4):69-78.

Isakov, Yu. A. 1966. Problems concerning the typology and evaluation survey of waterfowl habitats, pp. 67-72 In E. Carp (ed.), Proceedings of the Meeting on International Cooperation in Wildfowl Research, Jablonna near Warsaw, Poland, Int. Waterfowl Res. Board, Slimbridge (Glos.), England.

Ratcliffe, D.A. (ed.). 1977. A Nature Conservation Review: The Selection of Biological Sites of National Importance to Nature Conservation in Britain. Cambridge Univ.: London, Cambridge, and New York. Vol. 1, 401 pp., Vol. 2, 320 pp.

Szijj, J. 1972. Some suggested criteria for determining the international importance of wetlands in the Western Palearctic. pp. 111-119 In E. Carp (ed.), Proceedings of the International Conference on Conservation of Wetlands and Waterfowl, Ramsar, Iran, 1971. Intl. Waterfowl Res. Board, Slimbridge (Glos.), England.

THE CANADIAN EXPERIENCE: AN APPROACH TOWARD BIOPHYSICAL INTERPRETATION

Dennis A. Demarchi and
Thomas W. Chamberlain
Resource Analysis Branch
British Columbia Ministry of the Environment
Victoria, British Columbia, Canada

Abstract: Fish and wildlife habitat inventory in Canada has evolved from single-use capability classifications to biophysical-base data descriptions capable of a variety of resource interpretations. Key aspects of this evaluation have been the design of inventory systems to match our needs, a careful correlation of objectives and inventory scales, and the separation of specific interpretations from the habitat characteristics upon which they are based. Major deficiencies still exist in understanding how fish and wildlife systems interact with other resources, and in creating administrative systems capable of handling these interactions.

WILDLIFE SYSTEM INVENTORY AND DEVELOPMENT

INTRODUCTION

Wildlife in Canada and the conditions that govern its existence present a very complex subject for inventory and other forms of evaluation. Such work is often made more difficult by the impacts of other resource uses such as forestry and domestic livestock grazing, by natural variations in species distribution and abundance, and by social and economic concerns that influence resource developments. Often information relative to the numerical status of a resource, such as wildlife, is less needed by the resource manager than the body of biological, physical, social, and economic values which can provide choices for the use of land.

Under these circumstances we have viewed wildlife inventory less as an aggregation of facts about the distribution and abundance of existing animal populations, but more from the viewpoint of the ability and limits of natural land units to produce wildlife (under given levels of management and combinations of resource uses). Such land units are defined according to their physical features such as landforms and soils, to climate, and to natural vegetation. These features determine the status of wildlife but are often modified by a number of less permanent influences such as resource uses, weather extremes, and responses of animal populations to environmental changes that in many cases are amenable to some degree of control through management.

CANADA LAND INVENTORY

Land competition for alternative uses and increased economic and social planning by government in rural areas made apparent the need for improved knowledge of the productive capability of Canada's lands as well as their location and extent. Since World War II Canada has been abruptly transferred from a primarily agricultural-forest based economy to an urban-industrial based economy. This change, which is creating more change itself, is having a profound influence on our use of, and demands on, land and its renewable resources.

The delegates to the 1961 "Resources for Tomorrow" Conference held in Montreal strongly recommended a land capability survey for Canada. This program was undertaken as a cooperative federal-provincial program and was administered under the Agricultural Rehabilitation and Development Act (ARDA) of June 1961. The terms of reference, organizational form, and financial and administrative capability to carry out what was to become the Canada Land Inventory Program (CLI) were established in 1962. Criteria for wildlife capability mapping were developed by officials of the Canadian Wildlife Service and the Provincial game agencies. The mapping program for waterfowl capability was implemented by the Canadian Wildlife Service, while ungulate capability mapping was conducted by Provincial agencies (The Canada Land Inventory 1970, Rees n.d.).

It is important to understand that the Canada Land Inventory was the first attempt to classify, on a national basis, the capabilities of the land base for agriculture, forestry, recreation, and wildlife. The study encompassed nearly 1 million square miles (1,609,000 km^2), including all of the Maritime provinces and the settled portions of Ontario, Quebec, and the Western Provinces. For these reasons, classification systems covering each of the above were of an interpretive nature, relying upon the collation, revision, and interpolation of existing information. In addition to reconnaissance for inventory purposes, surveys were used to update information, fill in gaps, and to spot-check assigned ratings. The completed inventory was eventually published in map form and comprised the most reliable information available at the time.

In view of the need to ultimately consider alternative uses of land, the Canada Land Inventory capability classifications chose to ignore present ownership and land use. Capability ratings were established on the basis of ecological conditions which could be expected to prevail if the land under consideration were to be established for the primary purpose of producing wildlife. However, there were some necessary exceptions since some major, long-lasting human influences are virtually irreversible. In such instances, capability ratings were assigned on the basis of modified conditions rather than on pristine conditions. Also some agricultural practices have occurred over large areas and were considered as a permanent limiting factor to some ungulates (Benson 1967, Perret 1969). For example, the Prairie grain belt was not rated for buffalo (*Bison bison*); nor was the Fraser River Delta farmland assessed for elk (*Cervus canadensis roosevelti*). Similarly, cities, towns, villages and densely populated urban areas, where the current utilization for wildlife production is prohibitive, were omitted from consideration in the capability classification.

The inventory of wildlife under early Canada Land Inventory programs was limited to classifications of land capabilities for wild ungulates and waterfowl. This does not mean other groups of wildlife were not considered important but rather that the above selected groups held a generalized public appeal and a wide national distribution.

A map scale of 1:125,720 or 1 inch equals w miles (3.22 km) was chosen for a field inventory scale and a map scale of 1:250,000 or 1 inch equals 4 miles (6.44 km) was selected for data presentation.

The land capability classification that was developed reflected the physical characteristics of land units, as well as climatological and other factors which influence wildlife. The classification system was based on seven categories of capability ranging from "very good" with no significant limiting factors for wildlife production to "very poor" with no wildlife production being possible.

Each map area was inventoried by a system of ground counts, fixed-wing flights in the winter months, browse surveys, pellet group counts, and interviews with knowledgeable people. This process allowed us to determine what was occurring and what had occurred on a site, but not necessarily what could be produced on that site. Thus, in effect, we were at least able to use the capability classification process for rating the distribution and abundance of current wildlife populations. However, with careful extrapolation and interpretation, we were also able to predict and rate on a national level the ultimate distribution and abundance of our wildlife populations.

Implicit in the capability classification program was the fact that the data input was useful for land use planning when comparing various resources on a municipal, provincial, or Federal level. However, it did not provide the detailed information required for land management of individual parcels of land, nor for land planning in small watersheds. This might have been obvious from the scale of mapping and data presentation. Agencies that were pushing for the capability systems began either to use it for management decisions at a site specific level with maps enlarged eight times or to complain that the capability classification was a meaningless exercise because it did not give all the answers that users sought in wildlife management.

BIOPHYSICAL MAPPING

With the completion of the capability inventory and subsequent to interdepartmental pressures to provide inventory at a management level, we started the biophysical inventory program which is conducted at a scale of 1:50,000.

In British Columbia, we view the Biophysical Program as a building block process that encourages the synthesis of physical and biological data (landforms, surficial materials, soils, climate, vegetation, and organisms) to form "ecologically significant" units of the landscape. The process involves the delineation of various regional and unit level phenomena, each of which is an end-point for the appropriate discipline, but when combined provides the basis of the biophysical map unit.

No inventory procedure offers a fixed measure of the status or value of resources for all time. However, the biophysical concept of inventory does identify the more permanent natural physical factors that define land units. It also offers the best basis for measuring resource endowments, for appreciating resource relationships, and for assessing how these can be managed through various uses or combinations of uses.

After the biophysical base maps are prepared, they are used to map various land use interpretations such as wildlife, forestry, outdoor recreation, agriculture, irrigation, urban development, and road construction. For wildlife, these interpretations involve an assessment of current distribution and abundance by winter counts, pellet group counts, browse surveys, and accumulation of "local knowledge" through interviews with local biologists, wildlife consultants, guides, trappers, and knowledgeable outdoorsmen. We then extrapolate, based on our biophysical data base, to areas that do not have a particular wildlife species but hold the capability, usually through the modification of vegetation succession, to support that species.

Biophysical factors can be used to predict plant succession and the beneficial or harmful effects of burning, logging, or grazing. Similarly erodibiity and moisture regimes can be predicted. Thus, we also can use such predictive methods for future wildlife management options with the tools of burning, logging, grazing, etc. (or other treatments).

It is important to note that whereas the CLI program outlined capability classes based on biomass of the three dominant ungulates, the biophysical inventory allows the opportunity for assessing land for any species or subspecies occurring in the map unit.

Each species is given its own rating (Table 1, Figure 1), so little confusion remains as to the relative value of a geographic area to sustain a species. There is also the added benefit of providing species diversity as a mapping characteristic which was not previously allowed.

AQUATIC SYSTEM INVENTORY AND APPLICATIONS

HISTORY

The inventory of aquatic systems under early Canada Land Inventory programs was limited to descriptions of fisheries capability at a scale of 1: 250,000. Although applied to some eastern provinces (Nova Scotia, New Brunswick, Prince Edward Island, Quebec, and Manitoba), it was not extended to the west. As with the other elements of the CLI the four capability classes were oriented to a specific use (fish) and did not describe the system properties upon which these capabilities were based.

Since then some provinces, particularly Ontario and British Columbia, have developed aquatic systems surveys which emphasize more basic biophysical properties. In the case of Ontario, an evolution from "point in time" descriptions (principally lakes) oriented to specific management and research objectives has taken place, resulting in the present development of the Ontario Fisheries Information System. Since we are not familiar with its application, those interested should consult the Ontario Ministry of Natural Resources and Kerr and Neal (1976) or Loftus (1976).

In British Columbia, the aquatic system inventory was also initially concentrated upon lakes, no doubt as much because of their inventory tractability as their sport and commercial importance. A systematic program of lake survey was initiated in 1948 to provide basic fish, morphologic, and chemical parameters of the province's 16,000 plus lakes (for a summary see Balkwill 1972).

Stream surveys in the province have been conducted at various levels of intensity, beginning with rather crude estimates of salmon escapements and associated spawning grounds in the early 1900s by the Department of Fisheries (now Fisheries and Marine Service, Environment Canada). Since then we have experienced a gradual expansion of stream users, accelerating to the intense

Table 1. Biophysical Capability Classes for Wildlife (Ungulates) Carrying Capacity Estimates (Animals/Square Mile/Year) (Luckhurst 1975)

Classes[a]	Black-tailed deer (*Odocoileus hemionus columbianus*)	Mule and white-tailed deer (*Odocoileus hemionus*) and (*O. virginianus*)	Mountain sheep (*Ovis canadensis* and (*O. dalli*)	Elk (*Cervus canadensis*)	Caribou (*Rangifer tarandus*)	Goat (*Oreamnos americanus*)	Moose (*Alces alces*)
1C	88-105	69-83	53-63	43-51	31-38	24-29	19-23
1B	70-88	55-69	42-53	34-43	25-31	19-24	15-19
1A	53-70	41-55	32-42	26-34	19-25	14-19	11-15
2	35-53	28-41	21-32	17-26	13-19	10-14	8-11
3	18-35	14-28	11-21	9-17	6-13	5-10	4-8
4	4-18	3-14	2-11	2-9	1-6	1-5	1-4
5	<4	<3	<2	<1	<1	<1	<1
6	0	0	0	0	0	0	0

[a] Ranges calculated to the nearest 1.0 using the maximum of Class 1A as 100 percent.
Classes 5 to 1A respectively are: 5 percent, 5-25 percent, 25-50 percent, 50-75 percent, 75-100 percent.
Superclasses 1B and 1C calculated by adding 25 percent and 50 percent, respectively, to the 1A maximum value.
Mean values in brackets.

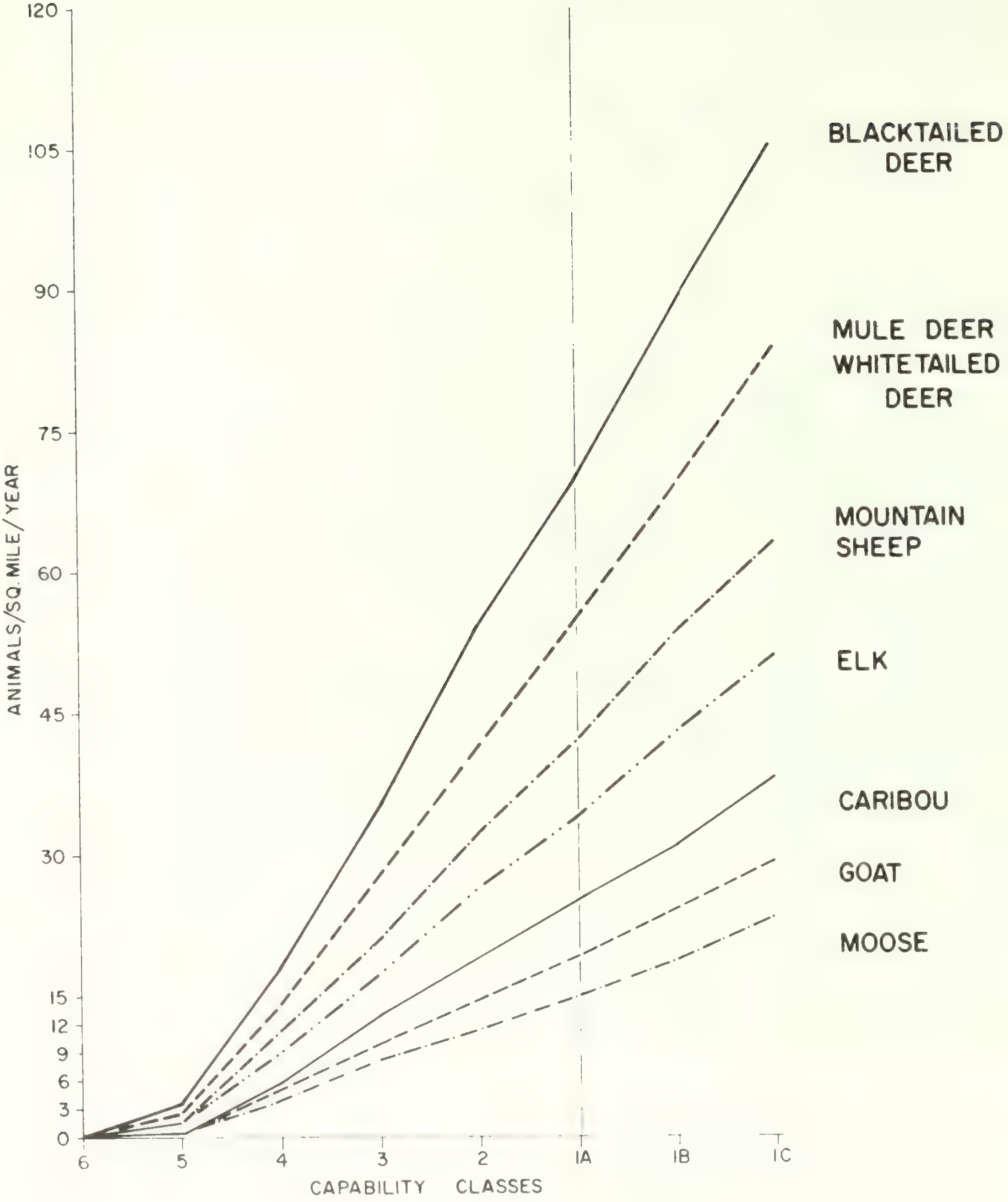


Figure 1. Comparison of ungulate capability classes by species -- plotting upper class values (Luckhurst 1975).

present day competition between fish, forestry, domestic, industrial, and agricultural water resources. This has produced a variety of specific resource-oriented stream surveys, principally in response to the needs of fisheries management agencies. Generally, these surveys have been conducted on an "ad hoc" basis, and oriented to habitat protection and forestry planning needs.

In conjunction with a significant acceleration of the province's forestry planning process in 1973, a framework for systematic stream inventory was established, and the first attempts were made to describe a wider range of habitat properties.

In 1974, a group of biologists and hydrologists was incorporated into the Resource Analysis Unit of the Environment and Land Use Committee Secretariat and instructed to design an inventory system which would provide systematic reconnaissance level (1:50,000) data of use to a wide range of resource managers.

The system which emerged drew heavily on the earlier experience of the Fish and Wildlife Branch and the Federal Fisheries and Marine Service, but attempted to also consider nonfish parameters of relevance to recreationists, engineers, and other nonfish users of the aquatic resources. A basic distinction was made in its inception between "basic" biophysical descriptions of the aquatic system (such as substrate, morphology, water chemistry, populations, etc.), and the subsequent "emergent" properties of the system (such as stability, productivity, and capability). The selection of relevant descriptors was, of course, predicated upon a paradigm of users' needs and was assisted by a workshop at which all of the active stream inventory agencies in the province participated.

The result is a system of 1:50,000 maps which describe "reaches" of streams and a variety of "point" features (Figure 2). The maps are supplemented by a data file listing a fuller range of sampled and inferred properties of points, reaches, and systems, organized hierarchically by watersheds. A description of the basic mapping system is contained in Appendix A, and Figures 3 and 4 show the field point and reach summary data cards which form the basis for the data file.

These data are supplemented with discharge measurements, where available, gathered by the Provincial Water Resources Service and the Federal Water Management Service. Unfortunately, the network of hydrometric stations in British Columbia is still insufficient for most "small" stream applications. This is even more true in the case of surveys of water quality and bed material transport, for which very few regional generalizations can be made.

APPLICATIONS

Two principal interrelated factors have influenced the application of our approach: user objectives and scale. It is clear that the complete coverage of British Columbia will not be possible at all levels of user objectives. Nevertheless, the primary scale chosen (1:50,000) provides information about most specific streams managed, as well as being capable of generalization for regional planning.

A team approach and extensive use of aerial photography and helicopter access has allowed coverage of over 100 map sheets in the 2 years since the system's inception. Interpretations have included urban suitability analyses

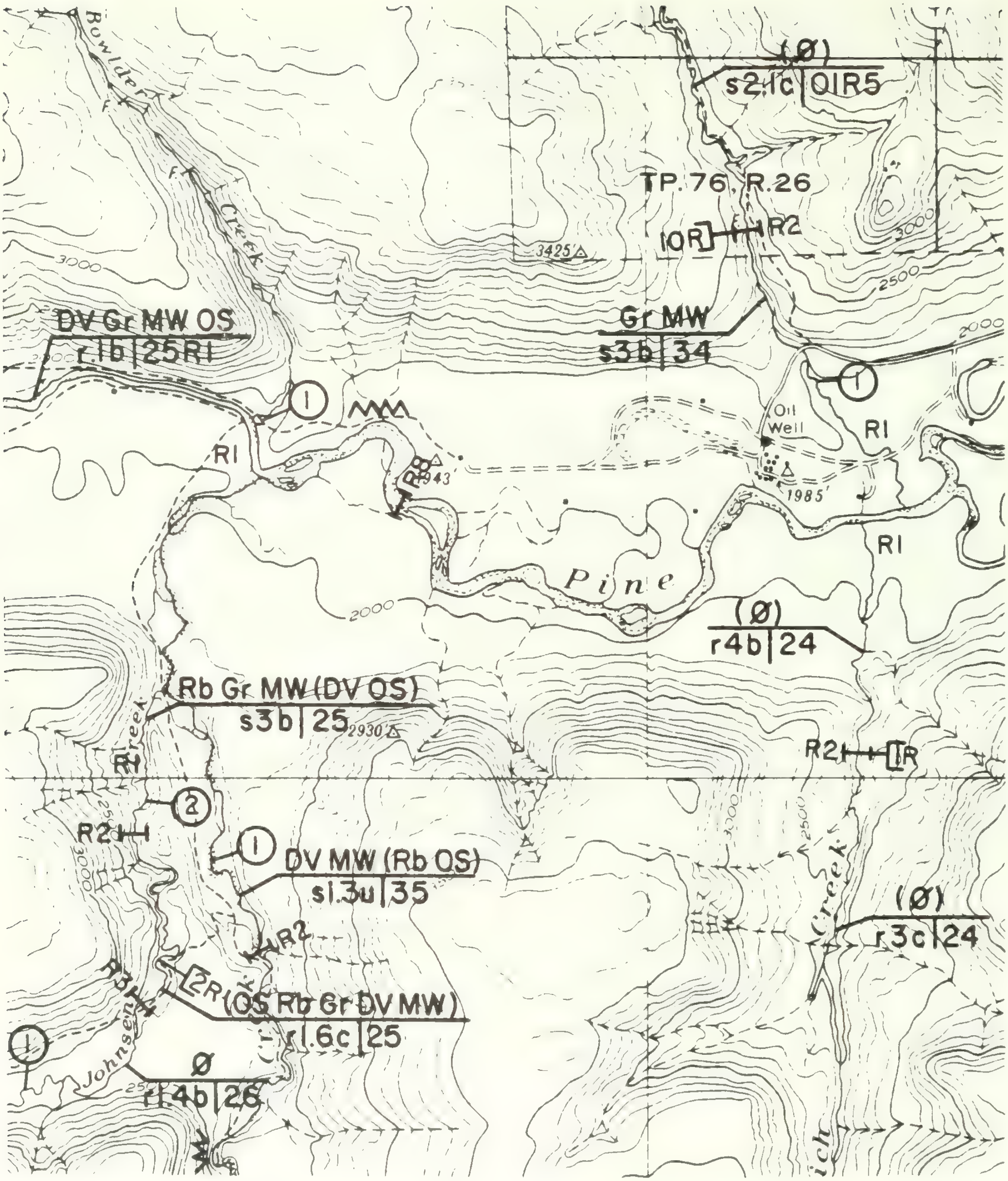
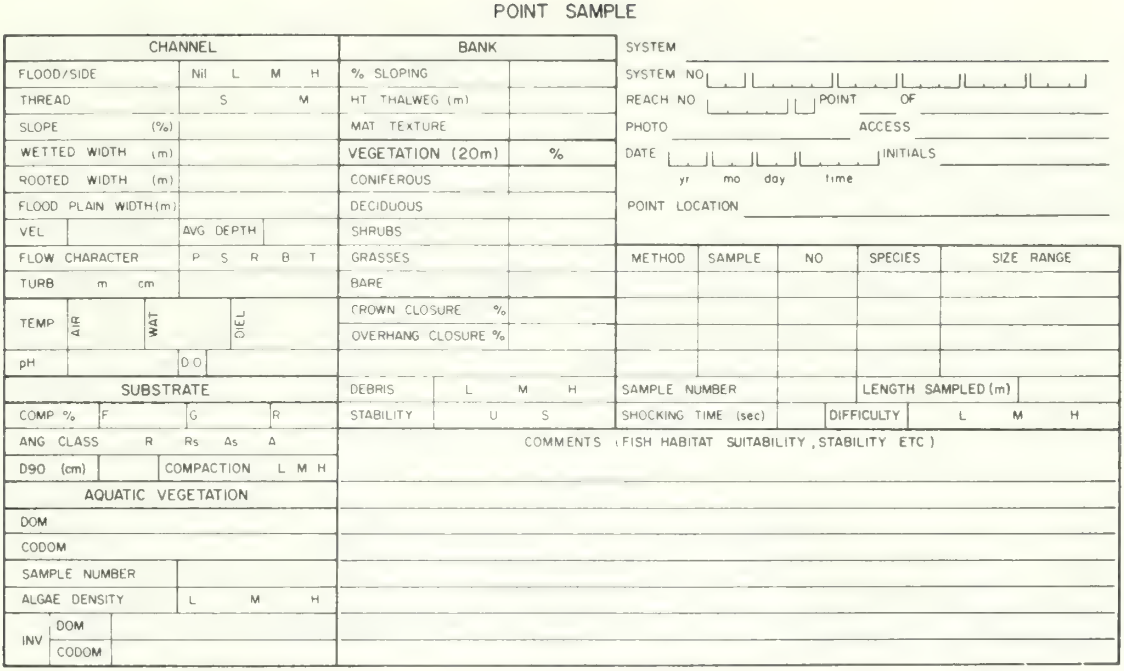


Figure 2. Example of section of aquatic biophysical map.



POINT SAMPLE

CHANNEL		**BANK**	
FLOOD/SIDE	Nil L M H	% SLOPING	
THREAD	S M	HT THALWEG (m)	
SLOPE (%)		MAT TEXTURE	
WETTED WIDTH (m)		VEGETATION (20m)	%
ROOTED WIDTH (m)		CONIFEROUS	
FLOOD PLAIN WIDTH (m)		DECIDUOUS	
VEL	AVG DEPTH	SHRUBS	
FLOW CHARACTER	P S R B T	GRASSES	
TURB m cm		BARE	
TEMP AIR WAT DIEL		CROWN CLOSURE %	
		OVERHANG CLOSURE %	
pH	D O		
SUBSTRATE		DEBRIS	L M H
COMP % F G R		STABILITY	U S
ANG CLASS R Rs As A			
D90 (cm)	COMPACTION L M H		
AQUATIC VEGETATION			
DOM			
CODOM			
SAMPLE NUMBER			
ALGAE DENSITY	L M H		
INV DOM			
INV CODOM			

SYSTEM

SYSTEM NO

REACH NO POINT OF

PHOTO ACCESS

DATE yr mo day time INITIALS

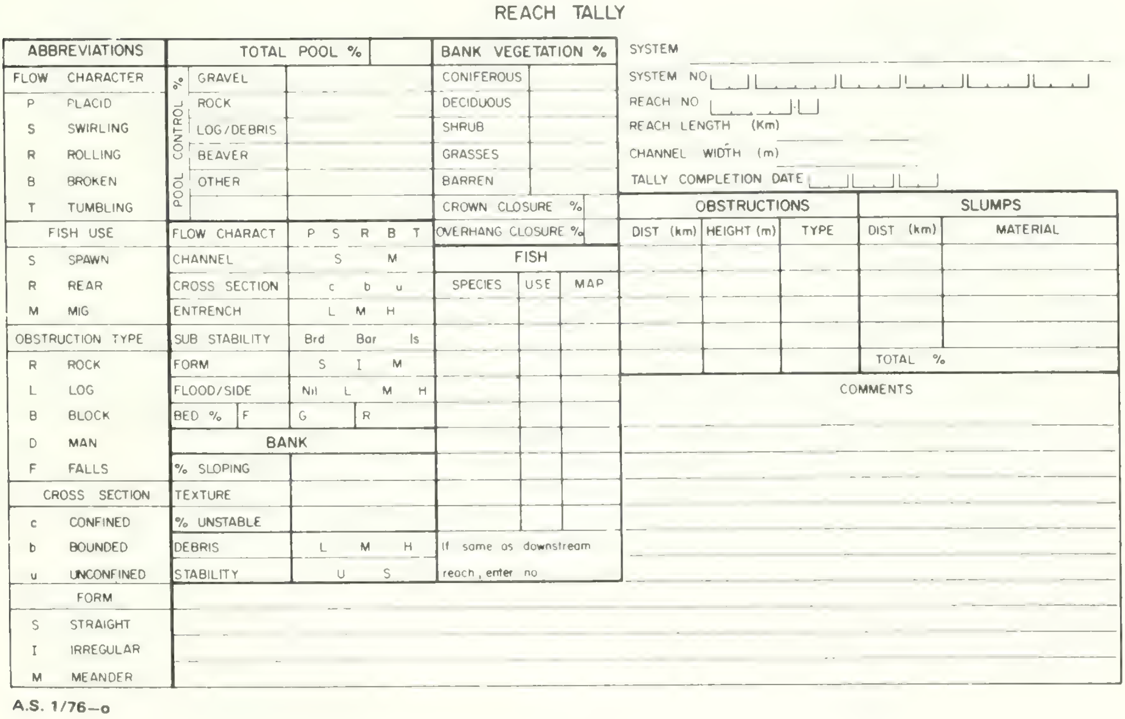
POINT LOCATION

METHOD	SAMPLE	NO	SPECIES	SIZE RANGE

SAMPLE NUMBER		LENGTH SAMPLED (m)	
SHOCKING TIME (sec)		DIFFICULTY	L M H

COMMENTS (FISH HABITAT SUITABILITY, STABILITY ETC)

Figure 3. Point data card.



REACH TALLY

ABBREVIATIONS	**TOTAL POOL %**		**BANK VEGETATION %**		
FLOW CHARACTER	POOL CONTROL % GRAVEL		CONIFEROUS		
P PLACID	ROCK		DECIDUOUS		
S SWIRLING	LOG/DEBRIS		SHRUB		
R ROLLING	BEAVER		GRASSES		
B BROKEN	OTHER		BARREN		
T TUMBLING			CROWN CLOSURE %		
FISH USE	FLOW CHARACT	P S R B T	OVERHANG CLOSURE %		
S SPAWN	CHANNEL	S M	**FISH**		
R REAR	CROSS SECTION	c b u	SPECIES	USE	MAP
M MIG	ENTRENCH	L M H			
OBSTRUCTION TYPE	SUB STABILITY	Brd Bar Is			
R ROCK	FORM	S I M			
L LOG	FLOOD/SIDE	Nil L M H			
B BLOCK	BED % F G R				
D MAN	**BANK**				
F FALLS	% SLOPING				
CROSS SECTION	TEXTURE				
c CONFINED	% UNSTABLE				
b BOUNDED	DEBRIS	L M H	If same as downstream		
u UNCONFINED	STABILITY	U S	reach, enter no		
FORM					
S STRAIGHT					
I IRREGULAR					
M MEANDER					

SYSTEM

SYSTEM NO

REACH NO

REACH LENGTH (Km)

CHANNEL WIDTH (m)

TALLY COMPLETION DATE

OBSTRUCTIONS			SLUMPS	
DIST (km)	HEIGHT (m)	TYPE	DIST (km)	MATERIAL
			TOTAL %	

COMMENTS

A.S. 1/76-o

Figure 4. Reach tally data card.

at a scale of 1:20,000 and regional stream capability classifications at a scale of 1:250,000, although the principal use has been for habitat protection aspects of the forestry planning process at a scale of 1:50,000.

In the application of the information we rely heavily on the complementary descriptions of water-related systems such as surficial materials, climate, and vegetation, but it must be concluded that an effective mechanism for integrating these data bases in British Columbia's resource management is still embryonic.

In the last few years, an increasing demand has arisen for out-of-stream hydrological interpretations. This demand, most usually generated by small water users, has encouraged the development of an interactive relationship between the pedologists, foresters, land use hydrologists, and biologists working in separate resource agencies; thus, there is some hope for the evolution of a true aquatic system inventory.

Efforts to date have ranged from detailed (1:5,000) descriptions of channel and riparian zone characteristics (similar to the approach of Dunham and his colleagues--see article this proceedings) to modifications of terrain classification systems oriented toward hydrologically relevant slope shapes and positions. Unfortunately the research establishment in British Columbia has not yet given land use hydrologic studies a priority equivalent to more production-oriented aspects of the resource base.

CONCLUSION

In British Columbia fish and wildlife exist largely in association with the productive forests that cover about 55 percent of the land area of the province and which are managed primarily for their commercial values. The social and economic commitment to forestry is a reality in the province and not likely to change, which is an inescapable fact with regard to management of wildlife. For this reason fish and wildlife cannot usually be viewed as primary crops of public lands; they are generally a secondary product of forest lands, and are most appropriately managed under objectives and programs designed to optimize the combined values of these resources as well as to maintain continued opportunities for their joint management.

Other resource commitments exist in the province that affect the fish and wildlife resources on a significant scale but which offer less opportunity for its active management or to enable public access to the resource. Agricultural lands are an example of importance on which the commitment to single purpose use under private ownership offers little security for fish and wildlife or opportunity for its management as a "public" resource.

It cannot be over emphasized that all applications of resource inventories have common ground in at least some of their biophysical components. Inventory in Canada has evolved from the single use capability classifications of the Canada Land Inventory Program to maps and data files capable of a broad range of resource interpretations of the biophysical program. This evolution reflects not only an improvement of our scientific understanding but also the social and political reality that an integrated approach to resource inventory is absolutely necessary for its application in resource management.

LITERATURE CITED

Balkwill, J.A. 1972. Limnological and Fisheries Surveys of Lakes in British Columbia, 1941-1971. Fish and Wildl. Branch, Dept. Recreation and Conserv., Fish Manag., Rep. 64, 53 pp.

Benson, W.A. 1967. Outline of the Canadian Land Capability Classification for Wildlife. Canada Land Inventory, Agricultural Rehabilitation and Development Act, Canada Department of Forestry, Ottawa. 20 pp. mimeo.

The Canada Land Inventory. 1970. Objective Scope and Organization. Canada Dept. Regional Econ. Expansion, Queen's Printer for Canada, Canada Land Inventory Rep. 1. Ottawa. 61 pp.

Kerr, S.R., and Neal, M.W. 1976. Analysis of large-scale ecological systems. J. Fish Res. Board Can. 33:2083-2089.

Loftus, K.H. 1976. A new role to fisheries management and F.E.J. Fry's role in its development. J. Fish. Res. Board Can. 33:321-325.

Luckhurst, A.J. 1975. Biophysical Land Capability Classification for Wildlife (Ungulates). E.L.U.C. Secretariat, Prov. British Columbia, mimeo rep. 30 pp.

Perret, N.G. 1969. Land Capability Classification for Wildlife. Canada Dept. Regional Econ. Expansion, Queen's Printer for Canada, Canada Land Inventory Rep. 7. Ottawa. 30 pp.

Rees, W.E. no date. The Canada Land Inventory--A conceptual framework for regional land use planning. Centre for Continuing Education, Univ. British Columbia, paper on local government 1(7):13.

APPENDIX A

AQUATIC SYSTEM MAPPING AND DATA MANAGEMENT

Draft Proposal, July 1976

INTRODUCTION

The following system is based on earlier proposals and includes definitions, methods, mapping conventions, and data processing requirements now being applied in Resource Analysis Branch directed inventory. Standardized field cards for reach and point descriptors are available to users who may wish to apply the system.

A basic and essential requirement for application of the system is that the user determine the scale of both the information being gathered and the problems to which it will be applied. For example, substrate descriptors will be quite different when inferred from 80 chain aerial photographs (Level I) as compared to the laboratory analysis of point samples (Level IV).

Table 1. Levels of Aquatic Systems Inventory

Level	Data Source/type/scale	Samples
I	Map/photo/fixed-wing. Presentation scale 1:50,000 - 1:250,000	None.
II	Point samples Species presence/obstructions Reach boundaries Presentation scale 1:50,000	Few samples. Point measurements. Reach parameter estimates.
III	Reach subsampled Habitat types described Population size estimated Presentation scale 1:20,000	Many samples. Reach parameter measurements. Large scale photos and walking transects.
IV	Time functions established Population ecology Detailed biophysical studies Presentation scale 1:5,000 - 1:20,000	Repetitive sampling. Experimental work.

---

[1] Revisions for larger scale applications and to accommodate data management requirements are under way. Persons wishing to examine the system in more detail should contact the Resource Analysis Branch, Ministry of the Environment, Victoria, British Columbia, Canada.

Generally, Levels I and II data are applied to problems involving regional values and comparison, choices between transportation corridors in different watersheds, the identification of major problem areas or types of problems, and the indication of area where more detailed sampling will be required. Level III data are usually needed for system-specific management prescriptions such as the evaluation of alternate mitigation or compensation measures, cutting plan layouts, or minimum flow estimates. Level IV studies will contribute to basic knowledge about specific aquatic systems and will lead to quantitative estimates of productivity and system stability, details of the life history productivity and system stability, details of the life history of various species, and an understanding of the interactions between components and processes of the aquatic ecosystem.

The glossary (Appendix 1--Appendices to this draft proposal are not included in the proceedings) contains a definition of all terms used in the system, together with the usual method of measurement or assessment. Where this changes with scale, it is so indicated. Arnette (1976)[1] has been followed whenever possible for definitions.

The complete system consists of a data bank and a map. All information on the map is in the data bank. The data bank is hierarchically organized by watershed system, reach, and points. Comments are stored verbatim. Water quality information is accessed by a cross-reference to a storage location in EQUIS (British Columbia Water Resources Service).

A code (Appendix 3) has been devised for watershed systems with the objective of providing a unique number for all third order or larger streams. Within systems, reaches are defined as the basic mapping unit and assigned characteristics based on point samples within the reach, aerial observations, and the interpretation of maps and air photos, as appropriate to scale.

Fish species are coded (Appendix 4) following Carl *et al* (1959)[2] together with the abbreviations of common names which are used in the mapping symbols.

The complete system is intended for application in all areas undergoing new inventory, or where a substantial data base already exists in fragmental form. Many areas in British Columbia will not have sufficient information to warrant using the system. When partial inventory is done, the system may be used in part. The map is intended to be fully understandable by the lay user, whereas the data bank contains those parameters normally required for interpretations by professionals involved in resource management.

We stress that the information is of the biophysical base; interpretations, which may vary regionally, should be considered separately as appropriate to the management problem. Following a year or two of application, the data bank parameters will be reviewed to assess their value. Inquiry is invited.

---

[1] Arnette, J.C. 1976. Nomenclature for instream assessments. Office of Biological Services. U.S. Fish and Wildlife Service. 7 pp.

[2] Carl, G.C., Clemens, W.A., and G.C. Lindsey. 1959. The freshwater fishes of British Columbia. British Columbia Provincial Museum, Ministry of Recreation and Conservation. 192 pp.

AQUATIC SYSTEM MAPPING

Map information is of two types: a reach symbol which summarizes some fish, channel, and substrate characteristics of the reach; and site specific symbols and information. The map base for presentation will normally be the 1:50,000 topographic series, with topography screened to 60 percent and other information (stream lines) screened to 80 percent. For 1:20,000 applications, planimetric bases derived from British Columbia Forest Service forest cover maps may have to be used. At larger scales (1:5,000), standard bases are not available but the use of topographic maps should be encouraged. Standard symbols are described first for 1:50,000 bases, with changes and additions at 1:20,000 indicated subsequently.

REACH SYMBOLS (1:50,000 base)

Reach symbols are applied to reaches, defined as sections of stream with relatively homogeneous properties. This definition is clearly dependent on the scale of observations and mapping. The properties most usually considered are slope, substrate, and channel cross-section, all of which are interrelated by the fluvial processes which create a drainage system.

Reach symbols are of the form:

$$\frac{\text{Fish Species}}{\text{Channel} \;\Big|\; \text{Substrate}}$$

except for headwater tributaries (see below), and are coded as follows:

Fish Species (Listed In Sequence)

1. Abbreviations are used for common sport and commercial species.

2. Known but nonsport or noncommercial species are indicated by the symbol OS (other species). The data bank must be consulted for the complete species list for the reach or system.

3. Fish observed but not identified are indicated by Sp.

4. 0 indicates that fish were not detected in the system at the time and place of sampling.

5. Absence of any fish species symbol indicates that no sampling information was available.

6. Symbols in parentheses (Co, St) indicate probable but unconfirmed presence, and would typically be used when fish have been sampled in a downstream reach and suitable habitat and access exist in the reach under consideration.

7. An arrow Sk↑ indicates that the reach is used by the species for migration only. It implies that the species does not have a resident population in the reach.

8. It should be noted that no specific symbol exists for a barren stream. When such a condition is suspected, it may be indicated by (Ø) which is an inference that if sampling took place, fish would not be detected.

Channel (Listed As Profile, Slope, Cross-section)

1. Profile (longitudinal) is either:

   a) stepped (s) (The cross section and substrate of stepped reaches may be complexed. Described below.)

   b) regular (r)

2. Slope is the average slope of the reach (length/elevation gain). Slope is given to the nearest percent above 3 percent and to the nearest 0.1 percent between 0 and 3 percent.

3. Cross section information will require careful consideration of the relative size of streams compared to the scale of base map. Three cross section types are differentiated at 1:50,000.

   a) confined (c) :

   b) bounded (b) :

   c) unconfined (u) :

Substrate

1. Substrate is identified by the percentage (nearest 10 percent) in three ranges, plus bedrock, of the top 20-30 cm of substrate material. These are defined as:

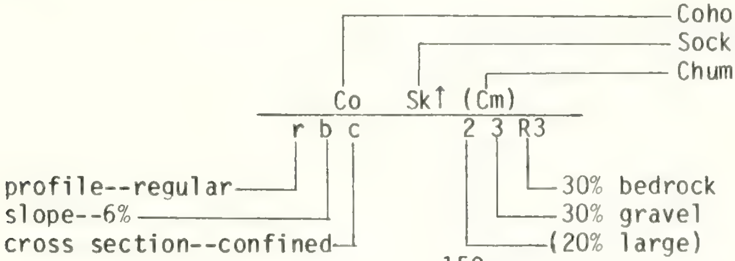
   Fines (0-2 mm)
   Gravels (2-100 mm)
   Larges (100+ mm)

   and represented by the first digit of the percentage (eg: 30 percent=3). Larges are not put in the reach symbol, but are inferred as a residual.

2. Bedrock percentage is indicated by Rn, where n is an integer representing the percentage of the reach whose substrate is bedrock. R without an integer implies 0--10 percent. For example, R2 implies that 20 percent of the reach substrate is bedrock.

3. When 90--100 percent of a reach is in one size category, F, G, L, or R is used alone.

Example:



Symbol Annotations And Conventions

1. Where the channel or substrate component is manmade, the symbol is underlined (e.g., $\underline{c}$ implies artificial channel confinement such as dyking).

2. Where data has not been verified (e.g., air photo interpretation of substrate composition) the symbol is placed in parentheses.

3. The reach symbol is applied to a stream segment as follows:

    a) Where both an upper and lower reach break symbol exist, the reach symbol applies to the mainstream segment so defined.

    b) Where the symbol is not so limited, it applies up to or down to the next tributary junction.

    c) In the case of a "Y" junction with reach breaks indicated in both arms the symbol applies to both arms.

4. For abbreviated symbols used in headwater classes (see below), the same conventions apply, except that the last (most upstream) symbol will apply to all tributaries above the last reach break.

Headwater Classes

An abbreviated symbol may be used in headwater situations where fish and substrate information is usually lacking. The symbol will include slope, cross section, and wetland class as follows:

1. Slope is either I (greater than 5 percent) or II (less than 5 percent).

2. Cross section is either c (confined) or u (unconfined).

3. Wetland class is either m (marsh), b (bog), f (fen), s (swamp), or p (pond).

A typical symbol might be Ic (b) which represents a steeply sloping confined channel, probably through an alpine bog.

The first 2 parts (slope, cross section) may be used alone.

Lakes

The inventory of lakes has received greater emphasis in British Columbia then have streams. Information resulting from standard lake surveys is cataloged by the British Columbia Fish and Wildlife Branch and should be consulted for details. On 1:50,000 aquatic system maps, lakes are treated as reaches and given a modified reach symbol:

$$\frac{\text{Fish (Total dissolved solids)}}{\text{Max. depth} \;\big|\; \text{Littoral area}}$$

where the following conventions apply:

1. Fish: as with streams;

2. TDS: total dissolved solids, if available;

3. Max. depth: as measured to nearest m;

4. Littoral area: where measurements or visual estimates are available, littoral area = percent less than 6 m in depth. When an estimate is made, it should be in parentheses, as stream inferences. Otherwise, it will be assumed that sounding transects have been made.

II SITE SPECIFIC SYMBOLS (Map Legend: 1:50,000)

A. REACH SYMBOL (Described in previous section)

Fish Species

Symbol	Species
Sp	Fish present; species undetermined
0	Fish undetected
OS	Species known but other than those listed
Ch	Chinook salmon
Co	Coho salmon
Cm	Chum salmon
Pk	Pink salmon
Sk	Sockeye salmon
Ko	Kokanee salmon
Rb	Rainbow trout
St	Steelhead trout
Ct	Cutthroat trout (coastal)
YCt	Yellowstone Cutthroat trout
EB	Eastern Brook trout
DV	Dolly Varden Char
LT	Lake trout
GB	German Brown trout
MW	Mountain Whitefish
LW	Lake Whitefish

Symbol	Species (Cont'd)
Gr	Grayling
LMB	Largemouth bass
SMB	Smallmouth bass
NP	Northern pike
WP	Walleye pike (Pickerel)
YP	Yellow Perch
Sg	Sturgeon
Bb	Ling (Burbot)
Cp	Carp

Symbol Annotations For Fish Species

$\overset{\uparrow}{(\text{Co})}$ Migration only: no resident population
Probable but unconfirmed presence

Channel Information

Profile
r: regular
s: stepped

Slope
nearest percent, greater than 3 percent
nearest 0.1 percent, less than 3 percent

Cross section
c: confined
b: bounded
u: unconfined

Substrate: ijRk

1. nearest 10 percent of i = 0 - 2 mm; j = 2 - 100 mm by first digit (e.g., 20 percent = 2); k = bedrock.
2. the size fraction 100 mm + is computed by inference.
3. when the substrate is 90 - 100 percent in one size category, F (0 - 2 mm), G (2 - 100 mm), L (100+ mm) or R (bedrock) is used alone.

Symbol Annotations For Channel And Substrate

1. (c) parameter inferred but not ground checked.

2. $\underline{c}$ parameter of artificial origin (manmade).

3. The channel cross section and substrate type may be complexed only if the profile is stepped. It is indicated as follows:

$\frac{c}{b}$: alternating confined and bounded sections.

$\frac{16}{R}$: alternating gravelly (10 percent 0 - 2 mm, 60 percent 2 - 100 mm) and rock (90 - 100 percent) sections.

B. HEADWATER TRIBUTARY CLASSES

Slope I: greater than 5 percent

II: less than 5 percent

Confinement: c: confined

u: unconfined

Wetland b: bog

f: fen

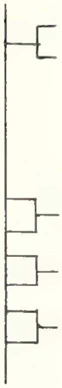
m: marsh

s: swamp

p: pond

eg: II c b: less than 5 percent slope; confined channel; bog. The wetland class may be left out if not applicable.

C. SPECIFIC SYMBOLS



3R........An obstruction 3 m high of the following types:

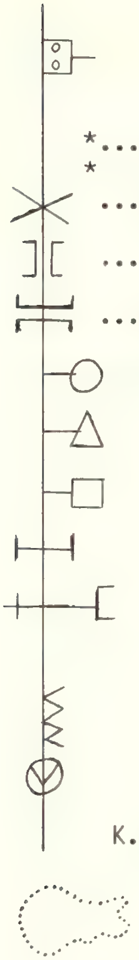
R (Rock), L (Logs), B (Blocks), D (Manmade),

Bd (Beaver dam), O (Culvert), F (Type unknown)

5R50......A chute or cascade 5 m high and 50 m long of the above types

C.........A chute or cascade with details unknown

Bd........A sequence of beaver dams



Ch........Clear evidence (eg: persistent redds or observed spawning adults) of spawning by the indicated species

*................A zone of flood and side channels
*

................A persistent debris accumulation

................A culvert

................A bridge

............A site (point) number with biophysical data available

............A water quality sampling site number

............A water quantity sampling site number

............A reach boundary

20R.......A reach boundary which is an obstruction. The obstruction height is not to be included in either adjacent reach for the purposes of reach slope calculation.

..........A major bank or valley side wall slump zone

............An alluvial sink hole without surface effluent

K.............A karst pothole

.........Persistent snow or ice

_______..........Major watershed boundary

___ ___..........Sub-watershed boundary

-----..........Minor watershed boundary. If a watershed boundary is mapped, that watershed has a code number and associated information in the data file.

U.S. FISH AND WILDLIFE SERVICE WETLAND CLASSIFICATION — STATUS, 1977

Lewis M. Cowardin
U.S. Fish and Wildlife Service
Northern Prairie Wildlife Research Center
Jamestown, North Dakota 58401

Abstract: The U.S. Fish and Wildlife Service is developing a new wetland classification for the United States. This classification will be used in an inventory which is being conducted. Its structure is hierarchical with five systems, Marine, Estuarine, Riverine, Lacustrine, and Palustrine at the highest level, and dominance types, based on dominant plants or animals at the lowest level. Users may select the level of detail appropriate to their needs. Earlier classifications do not furnish this detail or are not designed for the entire country. With modification the new system might be incorporated into a generalized classification of all land types.

This paper is a progress report on current wetland classification efforts within the U.S. Fish and Wildlife Service. A classification system is being developed and will soon be finalized. The classification is intimately connected to initiation of a national wetland inventory. I will confine my discussion to the classification. Work was initiated in January 1975 at a meeting of experts on wetland ecology and an outline was developed. A draft classification was prepared later and presented at the National Wetland Classification and Inventory Workshop (Sather 1976). Suggestions and criticisms resulting from this meeting were incorporated into an interim classification (Cowardin et al. 1976). To date a considerable volume of comment on this document has been received. In addition, the system was tested at sites throughout the United States during the summer and fall of 1976. Both the comments and tests identified problems and deficiencies that are being resolved. Although the basic structure of the classification is nearing finalization, publication of the system will not be complete until 1978.

Development of the classification has been a team effort. Advice was solicited and help gained from numerous individuals in the Federal and State governments, universities, and the private sector. Special credit is due V. Carter, F.C. Golet, and E.T. LaRoe who coauthored the classification with me. J.H. Montanarri furnished supervision of the entire effort and patiently kept us almost on schedule.

WHY A NEW WETLAND CLASSIFICATION

There are a number of reasons why a new wetland classification is needed; the most urgent is that some type of classification is prerequisite to the inventory and none of the available classifications appeared adequate. The last national inventory of wetlands, conducted by the U.S. Fish and Wildlife Service in 1954 (Shaw and Fredine 1956), was based on a classification developed by Martin et al. (1953). The classification was republished and illustrated in the former work and is commonly referred to as Circular 39. The system, composed of 20 types, was simple and has been used by the Fish and Wildlife

Service as well as other Federal and State agencies. Many users found it too simple for their needs and either modified the original system or developed completely new classifications. The system being developed should not be viewed as an immediate replacement for Circular 39. There will be a period of transition when both classifications are in use for specific purposes. Many of the types of Martin et al. (1953) have been incorporated in critical wetland legislation and must be cross-referenced to the new system.

Since 1954, there has been a tremendous increase in our understanding of wetland ecology and in public awareness of the value of wetlands. Workers in various parts of the country, who found the Circular 39 system inadequate, developed numerous regional classifications. Though frequently excellent in their own right (e.g., Stewart and Kantrud 1971, Golet and Larson 1974, Odum et al. 1974), these classifications differ in scope and rationale to such an extent that it is difficult or impossible to extend their use beyond their intended region or purpose. Several problems inherent in the classification described in Circular 39 led to its lack of acceptance by some and modification by others: (1) It was intended as the basis for a waterfowl habitat inventory and places greatest emphasis on wetlands used by waterfowl. (2) It does not allow for incorporation of detail beyond the 20 types described, and frequently value judgments or management decisions based on the types cannot be made. This is a serious problem even for waterfowl values in the production habitat of the prairie potholes. (3) The classes are not defined in detail and the system is often not applied consistently or objectively.

The new classification is intended to furnish a system that will: (1) have sufficient breadth to cover all types of land that have traditionally been called wetland as well as permanently flooded areas such as bays, sounds, and large lakes that were sometimes included and sometimes excluded from earlier classifications; (2) be hierarchical in structure and enable the user to select the degree of detail appropriate to needs, available knowledge, or technical feasibility for inventories; and (3) incorporate detailed definitions at all levels to insure standardization and uniformity of application.

PROBLEMS AND CONFLICTS

Before proceeding to a thumbnail sketch of the classification it would be useful to review some of the problems and conflicts that arose during its development and the reasons for decisions that were made. The subject of this symposium suggests that a classification of habitat should be approached from the holistic standpoint and that all habitats should be incorporated into a single framework. In fact, several papers recommend this approach. I personally am in agreement with this philosophy, but the administrative charge to the Fish and Wildlife Service was to conduct a wetland inventory, for which a wetland classification was needed.

When the classification was restricted to wetlands a definition became essential. The definition of wetland presented in the interim classification is based on the vegetation and soils present. Historically, this has been the traditional way of defining wetland but unfortunately wetland plants are usually defined as those plants occurring on wetland (e.g., Sculthorpe 1967:6), thus creating a circular definition. To break this circularity, it is necessary to develop a list of wetland plants as well as a list of wetland soils.

Work on these important tasks, which will have significant legal ramifications, is underway but will probably require as much as two years for completion.

Nearly all wetland classifications divide wetlands into categories according to vernacular terms such as marsh, bog, meadow, and swamp, etc. Definitions that conform to local usage are then added. Use of these terms leads to futile semantic argument because one man's bog is another man's pocosin. A swamp in the south may be a fen in the north. Even the scientific literature was little help because it is possible to find any number of conflicting definitions. Somewhat reluctantly, the authors of the classification decided to eliminate all vernacular terms for vegetated wetlands and rely on more universally accepted terms for plant life form such as forested, scrubshrub, and emergent.

From the standpoint of inventory it is important to elevate parameters that are easily detected on aerial photographs to a high level in the classification hierarchy. Unfortunately, easily detected features are not necessarily ecologically important. Grouping of wetlands into ecological systems at the top of the hierarchy made sense from the ecological viewpoint. This course of action was strongly recommended at the classification and inventory workshop. Spatial separation of these systems is very difficult. For example, some people separate estuarine systems from riverine systems at the limit of tidal influence while others make the separation at the limit of appreciable amounts of ocean derived salts. Either of these limits is exceedingly difficult to identify or to map. The new classification system furnishes a compromise between ecological importance and ease of inventory.

A similar type of problem arises because of the dynamic nature of wetlands. In many parts of the country wetlands go through extreme changes in a short period of time (Figure 1) and their average condition is more meaningful than their condition at any instant in time. Classes of wetland, such as "open water," that have been used in a number of earlier classifications are easily detected on aerial photographs but frequently have little ecological relevance. For this reason many of the elements in the new classification are based on average conditions and will present difficult problems to the photointerpreter. Knowledge of the local area, carefully selected dates of photography, or in some instances coverage on several dates, will be required for proper classification, by the new system, from remote sensing products.

Considerable confusion exists among users of classifications about whether an area within a basin or an entire basin is the unit being classified. When basins are small and discrete it makes sense to classify the basin. The classification developed by Stewart and Kantrud (1971) for the glaciated prairies is typical of such a system. When wetlands occur along rivers, on the shore of large lakes, or the sea, basin classification has little value. Since the new classification is designed for all wetlands, the elements classified are areas, rather than basins, and are equivalent to the zones in Stewart and Kantrud's (1971) classification.

Some systems like the new wetland classification are taxonomic (each taxon may be represented in many places); others (e.g., Bailey 1976) are regionalizations (each element has a unique location). Although the wetland classification is taxonomic, it is important to relate wetlands to a region of the country. The new system is, therefore, cross-referenced to Bailey's (1976) sections. Bailey's regionalization covers only land areas so provinces were added to his system for the description of coastal areas in the marine and estuarine systems. Recognition of regional differences is particularly important because the same

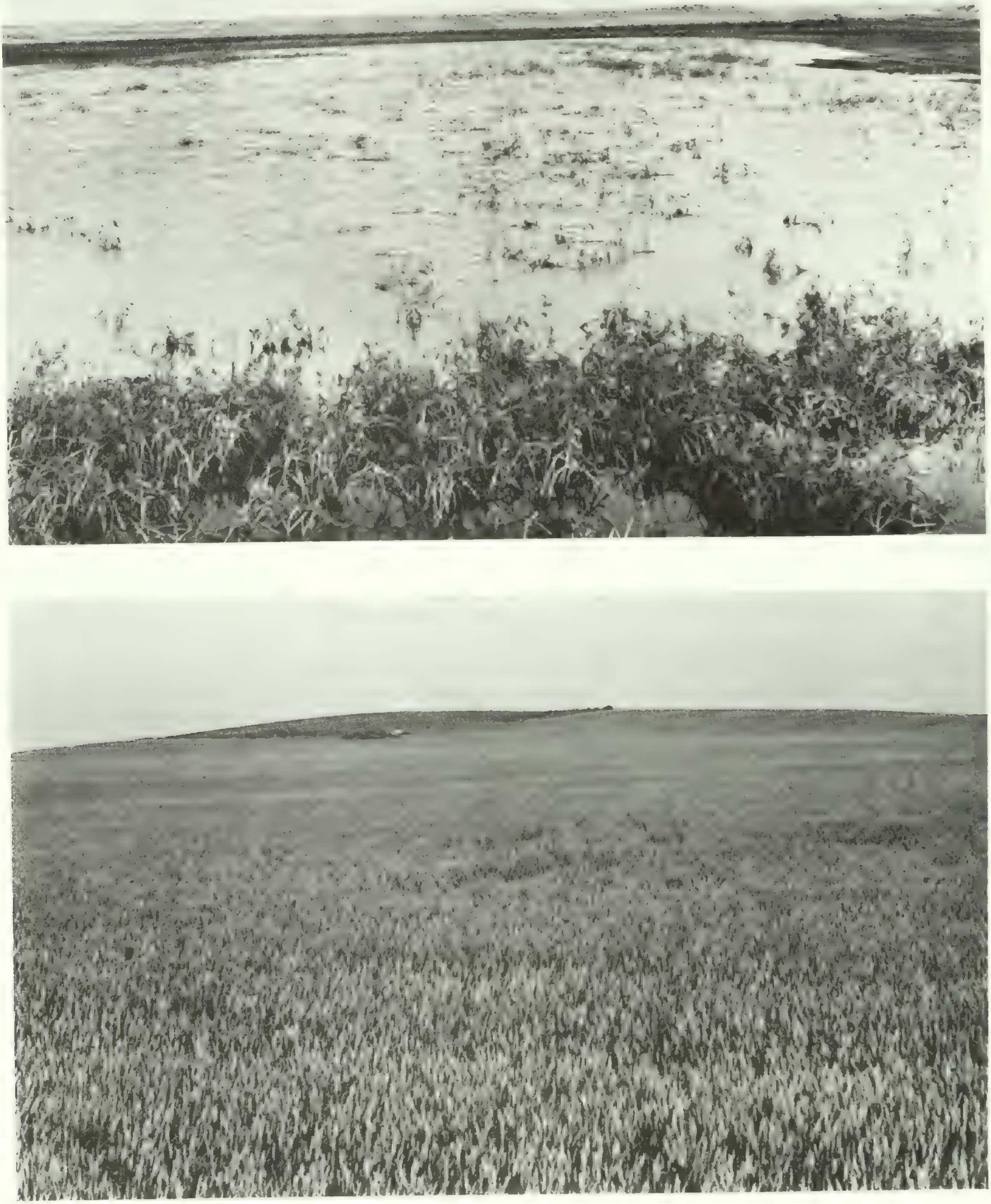


Figure 1. The same wetland in North Dakota photographed in November 1975 (top) and in July 1977 (bottom). This seasonally-flooded emergent wetland held water throughout the growing season and developed a stand of hydrophytic vegetation (Polygonum coccineum) in 1975. In 1977 the entire basin was farmed and planted to wheat (Photos by George A. Swanson, U.S. Fish and Wildlife Service).

plant or animal species may indicate different ranges in environmental factors in different regions of the country.

STRUCTURE OF THE NEW CLASSIFICATION

A detailed description of new classification is beyond the scope of this report and would be premature because modifications are still being made. I will attempt to describe the classification's general form, point out some problem areas, and contrast it to the system in Circular 39 (Shaw and Fredine 1956). At the top of the hierarchy, wetland and aquatic areas are assigned to one of five ecological systems: marine, estuarine, lacustrine, riverine, and palustrine. All of these systems represent concepts that have been accepted in the past. Despite general agreement on the concepts, writing the definitions which are essential to use of the classification is exceedingly difficult. The definitions, which place artificial boundaries on natural continua, are bound to appear stilted. All of the systems except the palustrine are divided into subsystems such as subtidal and intertidal. The subsystems again represent accepted groupings but their precise definition presented difficult problems.

Below the level of subsystem, wetlands are assigned classes that should be separable without detailed environmental measurements. Classes should be detectable from aerial photography taken at the proper season and used in conjunction with available supplementary data. Appearance is the key to separation at the class level and although the use of vernacular names was abandoned, the analogies are readily apparent. For example, most emergent wetlands are equivalent to marshes and most forested wetlands are equivalent to swamps. Classes were divided into subclasses where a logical separation has traditionally been recognized such as broad-leaved evergreen, needle-leaved evergreen, broad-leaved deciduous, and needle-leaved deciduous forested wetlands.

The classes or subclasses, where appropriate, were divided into dominance types which form the most detailed level of the classification. These are based on the dominant plant or sedentary animal species of the wetland. Dominance types are particularly important because the dominant species, in conjunction with knowledge of the ecological region, are important indicators of environmental parameters such as water regime and water quality.

The hierarchy described thus far does not furnish sufficient information to adequately describe a wetland. Additional detail in the classification is furnished through the use of modifying terms which are either taken from existing classifications or were developed and defined for this classification. I have already discussed the use of modifiers for ecological regions. Additional modifiers were developed for water regime, water chemistry, and special modifiers to describe modifications of wetland due to man's activity. Modifiers for soils were taken from the soid taxonomy (U.S. Soil Conservation Service 1975).

The general form of the system and its hierarchical structure are illustrated by two examples. Table 1 shows the classification applied to a California coastal marsh described by Vogl (1966) and a Minnesota bog described by Bay (1967).

Table 1. Examples of the Application of a New Wetland Classification to a Coastal Marsh Described by Vogl (1966) and Northern Bog Described by Bay (1967)

Categories	California Coastal Marsh (Shaw and Fredine 1956: Type 18)	Minnesota Bog (Shaw and Fredine 1956: Type 8)
System	Estuarine	Palustrine
Subsystem	Intertidal	Not Applicable
Class	Emergent Wetland	Shrub Wetland
Subclass	Narrow-leaved Emergent	Broad-leaved Evergreen
Dominance Class	*Spartina*	*Chamaedaphne*
Ecoregion	Californian	Spruce-fir
Water Regime	Regularly flooded	Saturated
Water Chemistry	Mixohaline	Fresh-acid

A LOOK TO THE FUTURE

Two types of general criticism of the interim classifications have been received: some reviewers found the structure too complex and technical; others, usually with specialized interests, found insufficient detail for their needs. I doubt that these conflicting viewpoints can be fully resolved in any classification. The new classification represents a "middle-of-the-road" approach and furnishes a hierarchical structure that allows the user to select the degree of detail necessary for his purposes. I hope that in the future a generalized system for all habitats will be developed and that the wetland classification will be compatible with it. It is encouraging to note that despite some problems, the wetland classification appears to be compatible with the natural area classification under development for the southeast and probably applicable over most of the United States (Radford 1977). As is the case with any new classification system, its value will not be fully known until after its application in the national inventory and as a tool in management of our wetland resources.

LITERATURE CITED

Bailey, R.G. 1976. Ecoregions of the United States. U.S. For. Serv., Ogden, Utah. Scale 1:7,500,000.

Bay, R. R. 1967. Ground Water in Two Peat Bogs in Northern Minnesota. Ecology 48:308-310.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. Laroe. 1976. Interim classification of wetland and aquatic habitats of the United States. Addendum, pp. 1-110 In J. H. Sather (ed.), Proc. National Wetland Classification and Inventory Workshop. U.S. Fish and Wildl. Serv., Washington, D.C.

Golet, F. C. and J. S. Larson. 1974. Classification of Freshwater Wetlands in the Glaciated Northeast. U.S. Fish Wildl. Serv. Resour. Publ. 116. 56 pp.

Martin, A. C., N. Hotchkiss, F. M. Uhler, and W. S. Bourn. 1953. Classification of Wetlands of the United States. U.S. Fish and Wildl. Serv. Spec. Sci. Rep. Wildl. 20. 14 pp.

Odum, H. T., B. J. Copeland, and E. A. McMahan. 1974. Coastal Ecological Systems of the United States. Conservation Foundation, Washington, D.C. 4 vols.

Radford, A. E. 1977. Natural Area Classification System: A Standardized Scheme. In Proc. Symposium on Classification, Inventory, and Analysis of Fish and Wildlife Habitat. U.S. Fish and Wildl. Serv., Office of Biol. Serv., Washington, D.C.

Sather. J. H. 1976. Proceedings of the National Wetland Classification and Inventory Workshop. U.S. Fish and Wildl. Serv., Washington, D.C.

Sculthorpe, C. D. 1967. The Biology of Aquatic Vascular Plants. Edward Arnold Ltd., London. 610 pp.

Shaw, S. P. and C. G. Fredine. 1956. Wetlands of the United States. U.S. Fish and Wildl. Serv. Circ. 39. 67 pp.

Stewart, R. E. and H. A. Kantrud. 1971. Classification of Natural Ponds and Lakes in the Glaciated Prairie Region. U.S. Fish and Wildl. Serv. Resour. Publ. 92. 57 pp.

U.S. Soil Conservation Service. 1975. Soil Taxonomy. U.S. Dept. of Agric. Agric. Handb. 436, Washington, D.C. 754 pp.

Vogl, R. J. 1966. Salt-Marsh Vegetation of Upper Newport Bay, California. Ecology 47:80-87.

DATA REQUIREMENTS FOR TERRESTRIAL WILDLIFE HABITAT INVENTORY

Richard Kerr and Kenneth Brown
Wildlife Staff, Bureau of Land Management
Building 50, Denver Federal Center
Denver, Colorado 80225

Abstract: The authors discuss rangeland resource inventories in the Bureau of Land Management since the Bureau's inception. The discussion relates the inventory components, necessary for wildlife habitat management, to this history and lists those elements or components of ecosystems that must be inventoried for evaluation of wildlife habitat.

On 28 June 1934 the Taylor Grazing Act (48 Stat 1269, 43 USC 315) was passed by Congress and signed into law by Franklin D. Roosevelt. Subsequent executive orders withdrew the public domain land from entry under certain agricultural and other disposal laws for classification and development.

By the early 1940's a few dedicated personnel provided by the Grazing Service started to inventory rangeland resources by vegetation type so that they could quantify annual amounts of forage produced and accomplish an adjudication of grazing privileges among qualified grazing applicants. While some of these inventories were relatively accurate, others were "broad typed" and of less value as a lasting resource inventory.

With the end of the Grazing Service and birth of the Bureau of Land Management (BLM) in 1946 these surveys continued and, when completed, the range was apportioned into grazing units.

A long history of legal precedence was set by administrative law judges and Federal courts when BLM used the range survey (Stoddart and Smith 1943) as a legal tool to set carrying capacity of the range.

In addition to forage information collected during the range survey, some information concerning animal use of the subtype was recorded on the back of the record forms. With this information and geographic seasonal locations given by State wildlife personnel, forage allowances could be made in the adjudication for big game animals. This action fulfilled BLM's requirement for wildlife under the Taylor Act which authorized cooperative agreements with State wildlife agencies (The Act of 28 June 1934).

In the middle 1960's adjudication of the range was considered completed by BLM and a technique of rest rotation grazing was used by BLM in administering its grazing authorizations. This system did not require the updating of vegetation surveys as the adjudication process had. Inventories based on vegetation typing essentially stopped as a BLM program at this time.

Meanwhile the national concern for our environment culminated in the National Environment Policy Act of 1969 which required that BLM look at total environment, not just habitat of big game animals.

The precarious status of national and international endangered wildlife species led, after a series of laws, to the Endangered Species Act of 1973.

Finally, the Federal Land Policy and Management Act of 1976 required BLM to "prepare and maintain on a continuing basis an inventory of all public lands and their resources, giving priority to areas of critical environmental concern. This inventory shall be kept current so as to reflect changes in conditions and to identify new and emerging resources and other values." (Public Law 94-579 Section 201, 21 Oct. 1976.)

These laws obviously require an appraisal of more than just big game habitat. In addition, litigation which has accelerated BLM's grazing program requires all types of wildlife information in order to anticipate impacts from grazing of domestic livestock. The endangered species program will require information for about 200 environmental statements for thousands of grazing allotments on over 40,460,000 ha (100 million acres). The time period for the program extends over a decade. The Bureau of Land Management has devised a system for inventorying habitat for mammals, reptiles, amphibians, fish, and birds on the public lands and has called it the Integrated Habitat Analysis System. The following discussion is a statement of the data elements required under that system for the terrestrial (including riparian) habitat inventory. We believe the collection of data listed is a minimum requirement for inventory of wildlife habitat.

It is our belief that inventory field data should be biotic and abiotic, factual information as opposed to judgments or interpreted information. That is, the composition of an ecosystem should be recorded, as opposed to the examiner's opinion of habitat as good, fair, or poor. These opinions are transitory and lose their value for future analysis, whereas, factual descriptors of ecosystem or community components can be used for various future interpretations.

Furthermore, we have based our discussions on the assumption that ecosystem components should be quantified within the boundary of a discrete geographically located ecosystem or natural cell. The rationale for this will be discussed later in this paper.

We also have based our ideas on the premise that complete inventory systems, run for each functional requirement of a land management agency, are inefficient if not prohibitive. Further, a large number of data elements necessary for each function can be accumulated by a coordinated resource inventory system. The BLM is now devising a coordinated resource inventory system under an effort known as the strategic plan for information systems.

In order to effectively collect wildlife habitat data on large areas of public land, as we have said, it is necessary to use a concept of a natural cell or geographic ecosystem within which to sample and quantify components.

For the boundary of our field data gathering unit we have chosen to use the stand, range subtype, or vegetation type. If a significant change in the composition, density, or structure of vegetation (aspect) can be discerned then the boundary is drawn on this division. If local landform modifies the vegetation so that animal occupancy or use could be affected, then the field cell boundary should be determined by the change in landforms. We call this natural field cell a habitat site.

Soil should be inventoried if possible and correlated with the above described cell boundary. This soil inventory is not absolutely necessary for wildlife habitat use, but the inventory is necessary for further use of the field cell by other disciplines or functions.

The data elements needed as a minimum habitat inventory and collected using the above described field cell are, in our opinion, the following:

- Cell area in acres
- Existing vegetation
    1. percent composition of the cover by species
    2. total percent of cover
    3. crown cover percent of shrubs and trees
    4. structure

- Local landform
    1. percent slope
    2. aspect
    3. elevation
    4. landform description--i.e., valley, hill, mountain
    5. topography (from U.S. Geological Survey Quadrangles)

- Animal occupancy and use within the cell
    1. animal species present
    2. use being made by each species
    3. verification of species occurrence
    4. tie to ecotones or neighboring cells
    5. density (general abundance)
    6. species features: caves for bat roosts, highway bridges used for swallow nesting, watering areas, etc.

- Juxtapositional values determined by field inventory
- Animal behavioral values determined by field inventory
- A regionalized ecosystem (cover type) formed by a group of field cells having similar vegetative potential

Boundaries of field cells are best established with the use of aerial photographs no smaller than 1:31,680 scale and field examination.

Perhaps the most important data elements determining importance of a field cell to wildlife are the samplings of vegetation. While some species such as sage grouse (*Centrocercus urophasianus*) (Wallestad 1975) or the chisel toothed kangeroo rat (*Dipodomys microps*) (K. Berry, personal communication) are tied to certain plant species for their requirements, we can look further and find that some are more related to the structure or seral stage of the vegetation rather than to specific plant species. The Montana Cooperative Elk-Logging Study (1976) stated "that plant community structure, or cover type is often a more important factor than community composition or habitat type in determining elk use during summer and fall." This link to structure is not reserved to large animals alone but in the preferences of the prairie longspurs we find McCown's longspur (*Rhynchophanes mccownii*) preferring low or heavily grazed grasslands while the chestnut-collared longspur (*Calcarius ornatus*) is attracted to taller grass types (R. Olendorff, personal communication, 1975). The integrated habitat analysis system records structure of forest and woodland by age classes and records brush and grassland by height.

Interacting relationships have been reported between animal use of vegetative types and landform. A Nebraska researcher (Sisson 1976) reported that "recent studies of habitat selection by birds indicated that selection is based on the 'physiognomy' or apparent characteristics of habitat such as landform or height and density of vegetation." -- "in the Nebraska Sand Hills, landform or topography plays a dominant role in determining the physiognomy of the habitat." -- "based on the findings of the present it was concluded that selection of habitat by sharp tailed grouse in the Nebraska Sand Hills is a function of the physiognomy of habitat determined primarily by landform and vegetation." -- "while sites used for some activities such as courtship and feeding were characterized by overuse by livestock, grouse selected lightly used or unused sites for nesting and loafing."

Data recorded during the site inventory includes a listing of the species present, indicates when use is linked to ecotones with neighboring sites, the season of use, any special uses made of the area (i.e., spring fawning), and a relative subjective indication of animal density.

The concept of "edge" as a value has been with the wildlife management profession since Aldo Leopold (1933) and perhaps before. Continuing demonstration of this occurs throughout research literature. Reynolds (1968) quantified it for mule deer (Odocoileus hemionus) in the southwest. "Natural forest openings furnish an important need for deer, elk, and turkeys. Deer prefer to feed 300 to 400 yards [274-366m] into openings from forest edges. Also they utilize openings created by clear cutting in dense forest stands. These research findings have encouraged land managers to remove invading timber production from natural openings to preserve them for game use."

This edge or juxtapositional value can only be measured by association specifically of various habitat sites and their relationship to their neighbors. Any system that does not allow for recordings of these values is leaving out a very critical habitat value. Often this value can be noted only by field examination of each habitat site.

Near Casper, Wyoming a place called Jackson Canyon became famous because it was a roosting place for wintering bald eagles (Haliaeetus leucocephalus) and golden eagles (Aquila chrysaetos) and a shocking number were found poisoned near the roosting areas. Prevailing winds in central Wyoming are from the west, from the Wind rivers to the hole in the funnel at Casper between the Bighorn Mountains on the north and Deer Creek range on the south. Tied into this stormy wind movement, which generally flows from the eagle hunting areas west of the North Platte River to Jackson Canyon, are the daily up flow patterns which last at least until sundown as they flow up the north face of Casper Mountain. There are thousands of acres of mature ponderosa pine (Pinus ponderosa) suitable for eagle roosting but roosting is concentrated on approximately 80 ha (200 acres). Jackson Canyon provides a gentle upslope lift to eagles returning from the hunting areas of the river and sagebrush grassland west of it. The highest west edge of the canyon provides an easy downward flight to the hunting areas the next day and the old ponderosa pines provide excellent roosting sites. Thus we have a prairie hunting ground, well grazed and normally blown clean from stormy westerly winds, with a river close by which happens to be on a southern migration route of eagles, next to a mountain covered with ponderosa pine for roosting, where there is an evening updraft to an undisturbed ridge that slopes westward toward the hunting country.

We know of no present data system that could have put all of these factors together and plotted the 80 ha roosting area on the west side of the canyon. Hence, we believe that many animal habitats require field survey and recording to determine their values, especially for the larger or more mobile species whose occupancy cannot be predicted as accurately as the small sedentary species.

Loveless (1967) described the complex interrelationships of habitat characteristics of a Colorado mule deer herd including animal relationships with topography, microclimate, and the vegetative matrix. His discussion of the importance of snow depth on deer movement and habitat use might be easily overlooked. Other researchers in Colorado (John Seidel, unpublished report, Colorado Div. Wildlife, 30 Apr. 1976) discussed complex juxtapositional relationships used for calving of elk. "The area of calving activity was located between 8,000 and 9,500 feet [2,438-2,895 m] in elevation...elk calving occurred in specific habitat types and on prepared beds that are used each year. The beds are found generally on south and east facing slopes of rolling hillock and aspen benches...beds are generally on a slight rise or on hillocks that afford a downhill observation...all beds were located within 200 yds [183 m] of water...they were located with 3/4 miles [1.2 km] from the winter range generally along a spring migration route."

Field inventory must also pick up habitat values found in certain sites and not others because of habit or animal behavior. Research has demonstrated that all suitable habitat, especially for larger species, will not be occupied if the animals have not learned to use it (Tueller and Monroe 1974).

Finally, the adoption of a regional geographical ecosystem of which the field cells are a part is absolutely necessary for the land manager so that he can quantify the amount of land in low seral, mid seral, or climax stages. Only in this way can the manager determine if he has the proper mixture of structure or seral stages. Diversity and health of the total wildlife population is dependent upon juxtaposition and diversity of seral stages within a potential or climax described ecosystem. Only with this information can the manager determine if he has the optimum cover/forage area relationship for elk, or the amount of habitat remaining for spotted owls (Strix occidentalis) which need old growth timber for their habitat (Zarn 1974).

The Bureau of Land Management has used the regional potential natural vegetation types of Küchler (1975) as our regional geographic ecosystems and further delineated them within physiographic regions to make them more geographically distinct.

The delineation of the field cells and their inventory for species and animal uses should be of immediate priority to assist in the performance of almost all jobs of concern within land management.

"It is widely assumed that we already have a basic inventory of North American fauna and flora, but this is far from completed. In the words of Frank Golley, Executive Director of the Institute of Ecology, "We don't even know how many species there are in the natural environment...we are tampering with systems that we don't even have a parts list for" (Finley 1976).

LITERATURE CITED

Finley, R. B. 1976. The values and uses of biological research collections. Shale Country, 29 November 1976.

Küchler, A. W. 1975. Potential Natural Vegetation of the United States. Map and booklet.

Leopold, Aldo. 1933. Game Management. Charles Scribner's Sons, New York. 481 pp.

Loveless, C. M. 1967. Ecological Characteristics of Mule Deer Winter Range. Colorado Game and Parks Dept. 124 pp.

Montana Cooperative Elk-Logging Study Group. 1976. Montana cooperative elk-logging study. Annu. Prog. Rep.

Reynolds, H. G. 1968. Healthy habitat. New Mexico Wildl. (Sept.-Oct.).

Sisson, Leonard. 1976. The sharp-tailed grouse in Nebraska. Nebraska Game and Parks Commission.

Stoddart, L. A. and A. D. Smith. 1955. Range Management. McGraw-Hill, New York. 433 pp.

Tueller, P. T. and L. A. Monroe. 1974. Management Guidelines for Selected Deer Habitats in Nevada. Univ. Nevada Publ. R104 Circa. 185 pp.

Wallestad, R. 1975. Life History and Habitat Requirements of Sage Grouse in Central Wyoming. Montana Dept. Fish and Game in Cooperation with Bur. Land Manage. 65 pp.

Zarn, M. 1974. Spotted Owl. Habitat Management Ser. for Unique or Endangered Species, Rep. 10, Bur. Land Manage. Tech. Note. 22 pp.

THE RPA-80 LAND CLASSIFICATION SYSTEM

Jack E. Schmautz
U.S. Forest Service
P.O. Box 2417
Washington, D.C. 20013

Abstract: The Resource Planning Act of 1974 directed the Secretary of Agriculture to assess the Nation's forest and rangeland resources in 1975, 1980, and thereafter at 10-year intervals. Since the assessments will use resource data from many sources, a national classification is needed. The classification to be used by the Forest Service in the 1980 assessment combines two existing classifications--the ecosystem classification developed by FRES and the ecoregion classification of Bailey. Purpose of the classification is to provide a common framework within which similar units of vegetation may be aggregated into groups called ecosystems, which in turn will be subdivided into four productivity and four condition classes. Estimates of present and expected production of herbage, plus browse and other resource outputs, will be made for each combination of ecosystem-productivity class-condition class. Integration of FRES ecosystems, Kuchler potential natural communities, and Bailey's ecoregions is also discussed.

INTRODUCTION

RESOURCE PLANNING ACT OF 1974

On 17 August 1974, Congress passed a law that will have a profound effect upon the management of renewable resources on lands administered by the U.S. Forest Service. This law, the Forest and Rangeland Renewable Resources Planning Act of 1974, better known as the Resources Planning Act, RPA, directs the Secretary of Agriculture to prepare an assessment of the Nation's renewable forest and rangeland resources. The assessment was to include:

1. An analysis of present and future uses, demands, and supplies of renewable resources,

2. An inventory of present and potential resources to be developed by the Forest Service and other Federal agencies, and

3. An evaluation of the opportunities to compare the yield of goods and services from those resources.

The first assessment was reported to Congress by 31 December 1975. A reassessment is to be completed in 1980 and each decade thereafter.

NEED FOR A LAND CLASSIFICATION SYSTEM

All of the Nation's forest and rangeland resources are to be assessed, not just those on lands administered by the Forest Service; thus, data from many sources must be used. Generally, the available data have been gathered under a variety of criteria and standards. A common framework is needed so the data may be compiled, analyzed, and displayed in a desired format. A national land classification would provide that framework.

RECOMMENDATIONS FOR RPA-79

For this framework the first assessment (RPA-75) used the ecosystem classification developed in 1972 by the Forest-Range Environmental Study, FRES (U.S. Forest Service 1972). The ecosystem classification covered only the 48 contiguous states.

A Forest Service work group, appointed by Chief John McGuire, recommended that the FRES ecosystem classification used in RPA-75 also be used in RPA-80 and that the classification include all states, territories, and possessions. Others recommended the FRES ecosystems be regionalized by using the ecoregion classification developed by Dr. Robert Bailey, Forest Service, Ogden, Utah (Bailey 1976).

As a result of these recommendations, a classification has been developed that will be used by the Forest Service in the 1980 assessment. I will describe this classification.

THE RPA-80 CLASSIFICATION

BASIS OF RPA-80 CLASSIFICATION

The RPA-80 classification is not new; it combines two existing national classifications--the ecosystem classification of FRES and the ecoregion classification of Bailey.

FRES CLASSIFICATION

The FRES ecosystems are based entirely upon vegetation. The forested ecosystems are the forest cover types developed and defined by Forest Survey (now called Resources Evaluation) of the Forest Service (U.S. Forest Service 1967). The nonforested ecosystems are based upon the potential natural plant communities, or phytocoenoses, developed and defined by Dr. A. W. Küchler, a plant geographer at the University of Kansas (Küchler 1970). Thirty-four ecosystems, each including one or more Küchler communities, were recognized in the 48 contiguous states.

Each ecosystem was further subdivided into four productivity classes and each productivity class into three condition classes. There were, then, 12 potential productivity-class condition-class combinations for each ecosystem. Each combination was called a resource unit. There were 408 such units, i.e., 34 ecosystems times 12 productivity-class condition-class combinations, in the 48 states.

For each resource unit, estimates were made of present production and the expected production of herbage and browse if certain management activities or strategies were applied to the resource unit. These estimates or coefficients were entered into a linear program modeling system, FREPAS. This enabled planners to make estimates of expected total production of herbage and browse if certain management strategies or mixes of strategies were applied to each of the various ecosystems. The accuracy of the predictions are, of course, dependent upon the accuracy of coefficients used.

BAILEY CLASSIFICATION

Dr. Bailey has already described his ecoregion classification and the criteria and standards by which he delineated the various levels of his classification; I need not repeat them here. Suffice it to say that his top three levels--domain, division, and province--are based upon prevailing climatic regimes, climates, and zonal soils. His fourth level, section, is based upon prevailing potential natural plant communities. Only the top four levels of his classification will be used in the 1980 assessment.

EXTENSION OF THE FRES ECOSYSTEMS

For RPA-80 the ecosystems have been extended to include all states, territories, and possessions. Fifty-five ecosystems are recognized--34 in the 48 contiguous states, 11 in Alaska, 7 in Hawaii, 2 in Puerto Rico and the Virgin Islands, and 1 in the Pacific Islands exclusive of Hawaii.

REGIONALIZATION IN RPA-80

PURPOSES OF REGIONALIZATION

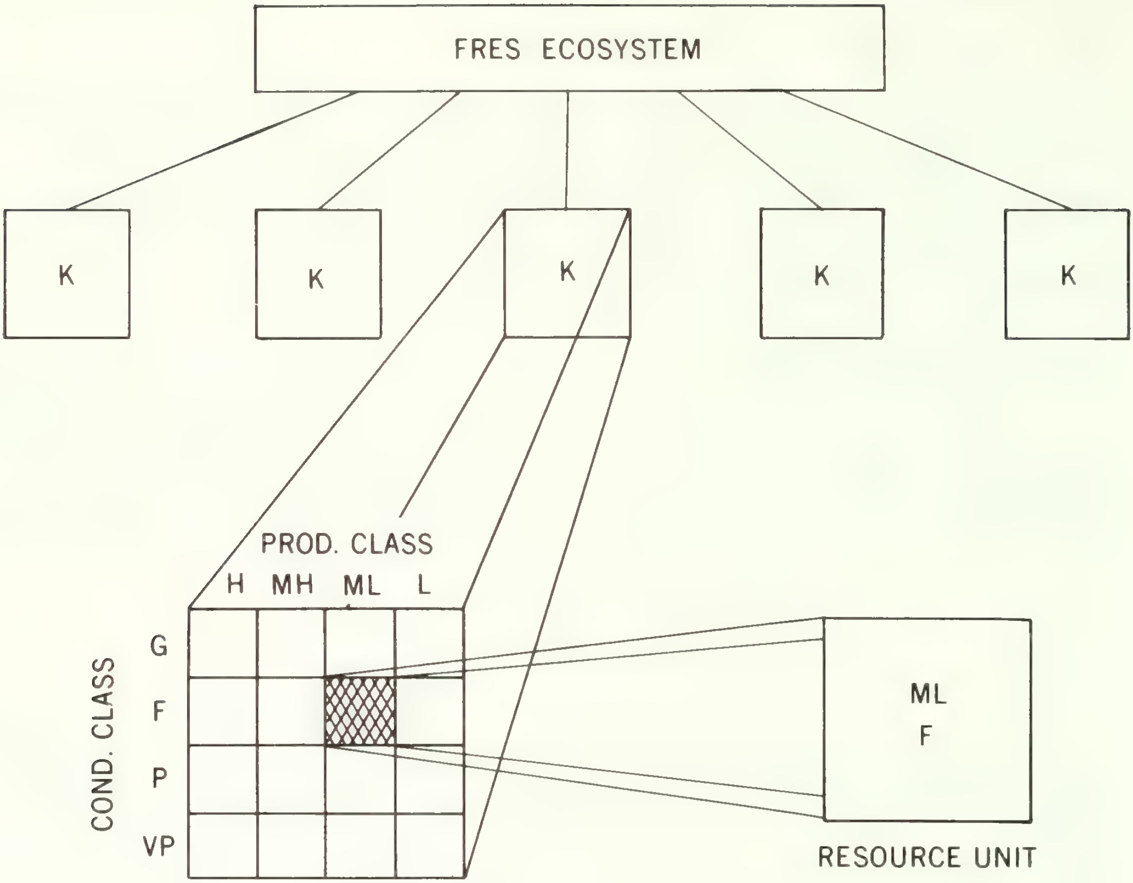
The production coefficients I referred to earlier are, in reality, averages for the resource units in the ecosystem. Some ecosystems, for example the plains grassland and the oak-hickory, occur over a large range of latitude, longitude, climates, and soils. Therefore, the coefficients represent large ranges in variation of production in reaction to management activities. Predictions, therefore, are quite gross. Reducing the range of variation in each resource unit should increase the sensitivity of the coefficients and, hence, increase accuracy and validity of the predictions.

This range of variation will be reduced by using Bailey's ecoregion classification to regionalize the FRES ecosystems.

FRES ECOSYSTEMS AND KUCHLER COMMUNITIES

As I indicated each FRES ecosystem was composed of one or more Küchler communities (Figure 1). For RPA-80 each Küchler community will be subdivided into four productivity classes, each of which will be subdivided into four condition classes. There will be, then, potentially 16 productivity-class condition-class combinations, i.e., resource units, for each community.

For the United States, 106 Küchler communities are recognized in the 48 states and 127 for the Nation as a whole. There will be 1,696 resource units (106 x 16) for the 48 states and 2,032 (127 x 16) for the Nation. For each resource unit production coefficients will be developed. It should be understood, of course, that all the coefficients may not be different.



TOTAL RESOURCE UNITS:

RPA-79 48 STATES = 1696

NATION = 2032

FRES 48 STATES = 408

Figure 1. Disaggregation of FRES ecosystems into resource units.

INTEGRATION OF FRES, KÜCHLER AND BAILEY

Now just how does this fit with Bailey's classification? You will recall that Dr. Bailey said his section was determined by the prevailing climax community, i.e., the Küchler community. It is at the section level, then, that the integration of FRES and Bailey's ecoregion classification will be made.

Perhaps the easiest way to explain the integration is to use an example. I will use K-101, the oak-hickory-pine forest, because it illustrates the points I wish to make.

First, K-101 is one of four Küchler communities that make up FRES ecosystem, number 13-loblolly-shortleaf pine (Figure 2). K-101 occurs in the following six of Bailey's sections:

2214 - Appalachian oak forest

2215 - Oak-hickory forest

2311 - Beech-sweet gum-magnolia-pine-oak forest

2320 - Southern mixed forest

2511 - Oak-hickory-bluestem parkland

2512 - Oak-bluestem parkland.

The sections occur in four provinces which, in turn, occur in three divisions, all in the 2000-humid temperate domain. In some sections K-101 is the major community, in others it is a minor one. As mentioned before, the principal factors that Bailey used to delineate his first three levels are: prevailing climatic regimes, climates, and zonal soils--all factors that profoundly affect productivity of a site. Therefore, it can logically be expected that the oak-hickory-pine community will be more productive in some of Bailey's sections than in others. It can also be expected that a higher proportion of the high productivity sites will be in sections with favorable climates and soils and a lower proportion will be in sections with less favorable climates and soils. The reverse should be true for the occurrence of low productivity sites.

This relationship is shown for K-101 using a hypothetical distribution of oak-hickory-pine sites by productivity class (Figure 2). A large proportion of highly productive K-101 sites will hypothetically be in sections 2214, 2215, and 2311. Most of the low productivity sites will be in 2511 and 2512. Thus one should be able to say "the production of herbage and browse in oak-hickory-pine sites in Appalachian oak forest climates and soils will be so much and in oak-bluestem parkland climates and soils it will be thus and so." The distributions (Figure 2) are hypothetical because I had no data, but they illustrate the principles.

The same relationships can be shown for other ecosystems such as plains grassland and sagebrush.

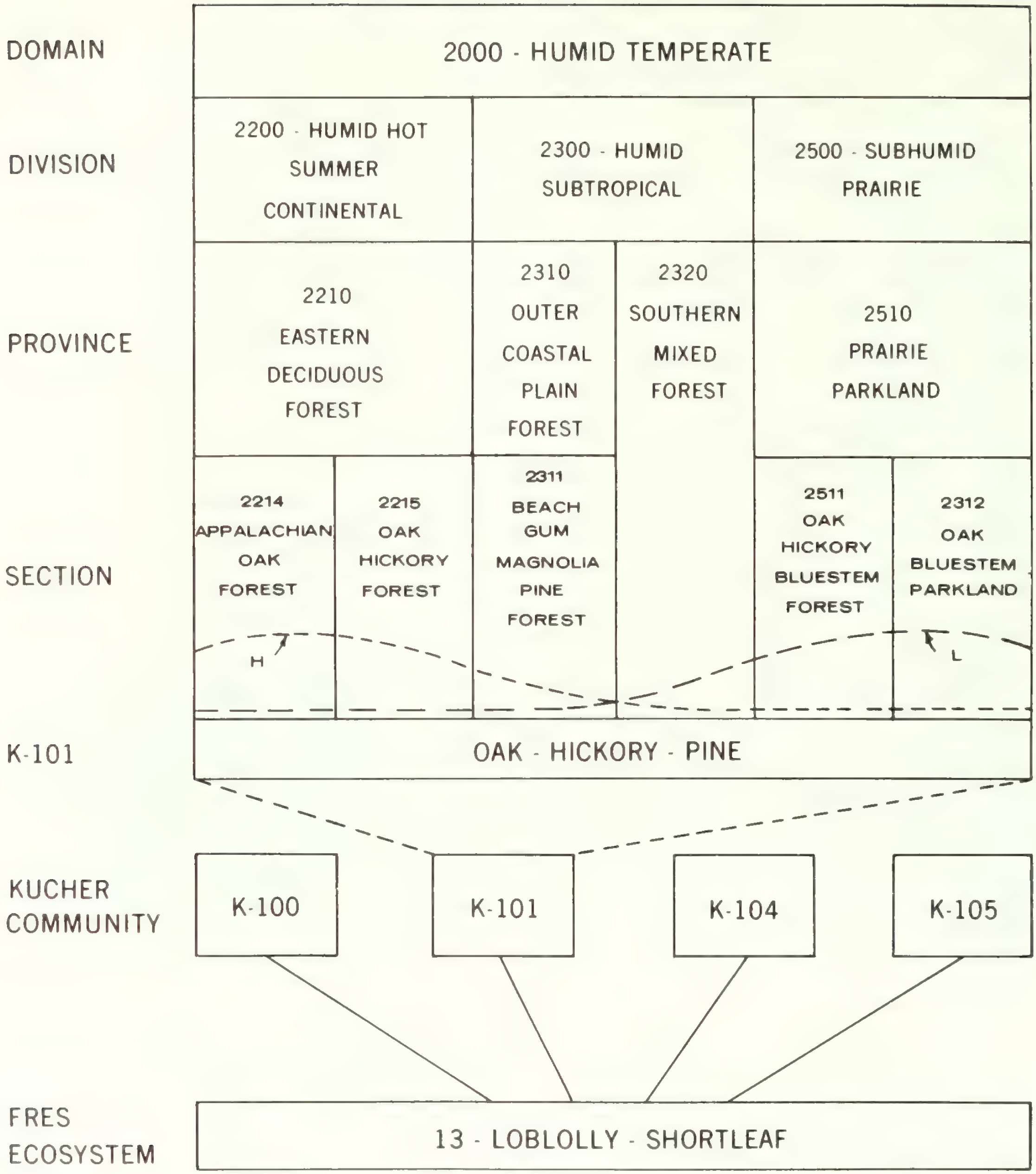

DOMAIN
2000 - HUMID TEMPERATE
DIVISION
2200 - HUMID HOT SUMMER CONTINENTAL
2300 - HUMID SUBTROPICAL
2500 - SUBHUMID PRAIRIE
PROVINCE
2210 EASTERN DECIDUOUS FOREST
2310 OUTER COASTAL PLAIN FOREST
2320 SOUTHERN MIXED FOREST
2510 PRAIRIE PARKLAND
SECTION
2214 APPALACHIAN OAK FOREST
2215 OAK HICKORY FOREST
2311 BEACH GUM MAGNOLIA PINE FOREST
2511 OAK HICKORY BLUESTEM FOREST
2312 OAK BLUESTEM PARKLAND
H
L
K-101
OAK - HICKORY - PINE
KUCHER COMMUNITY
K-100
K-101
K-104
K-105
FRES ECOSYSTEM
13 - LOBLOLLY - SHORTLEAF

Figure 2. Integration of ecosystems and ecoregions.

SOURCE OF COEFFICIENTS

Where will the coefficients come from? This is another story but, briefly, they will be developed at workshops which will be attended by people knowledgeable about the various plant communities. Attending the workshops will be people from Federal and State agencies, universities and colleges, representing a wide range of expertise.

SUMMARY

The FRES ecosystems have been extended from 34 in the 48 contiguous states to 55 in all states, territories, and possessions. The ecosystems will be subdivided into Küchler communities, 127 in all, and each community into 16 resource units. Herbage and browse production coefficients will be developed for each resource unit. Bailey's classification, to the fourth, or section level, will be used to help refine and explain these coefficients.

LITERATURE CITED

Bailey, R. G. 1976. Ecoregions of the United States. U.S. Forest Service, USDA.

Küchler, A. W. 1970. Potential Natural Vegetation, pp. 90-91. National Atlas. U.S. Geological Surv.

U.S. Forest Service. 1965. Forest Survey Handbook 4813.1.

U.S. Forest Service. 1972. The Nation's Range Resources--A Forest-Range Environmental Study. For. Resource Rep. 19, U.S. Dept. Agric.

A DIGITIZED CLASSIFICATION SYSTEM FOR THE NATURAL VEGETATION OF NORTH AMERICA WITH HIERARCHICAL SUMMARY FOR WORLD ECOSYSTEMS

David E. Brown
Arizona Game and Fish Department
2222 W. Greenway Road
Phoenix, Arizona 85023

Charles H. Lowe
Department of Ecology and Evolutionary Biology
University of Arizona
Tucson, Arizona 85721

Charles P. Pase
U.S. Forest Service
Arizona State University
Tempe, Arizona 85281

Abstract: The need for a hierarchical and systematic classification for ecosystems is presented with a proposed classification system. This system is based on the evolutionary criteria which determine the history, adaptations, structure and composition of plant and animal communities. It is a universal system ranking natural vegetation in systematized natural sets. Examples of a digitized computer compatible classification to the 4th (=biome) and 5th (=community) levels of the system are given for Nearctic and adjacent Neotropical North America.

The accelerated alteration and destruction of the earth's natural ecosystems has stimulated increased interest in the classification and mapping of our remaining living and therefore renewable resources. While the investigation, interpretation, classification, and mapping of various biotic units has long been progressing in Europe, in the Soviet Union, and in the United States, recent efforts in some of the "developing" countries indicate worldwide interest and activity in these endeavors (e.g., Aubreville et al. 1958, Fittkau 1969, Flores et al. 1971, Comision Tecnico Consultiva para la Determinacion Regional de los Coeficientes de Agostadero 1974).

These activities have prduced numerous resource classifications, particularly for vegetation. With some notable exceptions (e.g., Braun-Blanquet 1932, Daubenmire 1952, Gaussen 1953, 1955, Braun-Blanquet 1964, Ellenberg and Mueller-Combois 1967, Dasmann 1972) the classifications rest on limited criteria (Kuchler 1967) or on partly artificial criteria such as land use *per se* (Anderson 1971, Anderson et al. 1972).

Again with notable exceptions (e.g., Dansereau 1957, Fosberg 1961, Krajina 1965, International Union for Conservation of Nature 1973, 1974, Ray 1975), resource classifications and classification schemes tend to be regional rather than continental and worldwide in their approach and applicability. Moreover, some recently developed "wetland" classification systems, while otherwise excellent, may be cumbersome due to dependence on geologic and chemical criteria (e.g., Martin et al. 1953, Stewart and Kantrud 1971, Golet and Larson 1974, Cowardin et al. 1975).

Other proposed and excellent classification systems are non-hierarchical and therefore not readily subject to expansion and field modification (e.g., Wieslander 1935, Society of American Foresters 1954, Dansereau 1957, Garrison et al. 1976). This has resulted in resource management agencies combining and adapting various partial classification systems, with the result that no standardized system that is satisfactory is presently in effect within regions, much less throughout North America. In fact, there is yet no agreement even on the basis for a system of classification. That the need exists is well-known (National Environmental Policy Act 1969, National Resource Planning Act 1974); i.e., Layser 1974, Pfister 1975, USDA Forest Service 1977.

While botanists and zoologists have long recognized and utilized the natural order of hierarchical systematics based on evolutionary criteria, resource managers have yet to agree on an analogous evolutionary hierarchy for a natural universal classification system for communities of renewable resources.

The ecologic hierarchy herein ranks natural vegetative communities in systematized natural sets. This system is formulated on natural criteria and recognizes the limiting influences of moisture and temperature minima as well as the evolution of structure and composition of vegetation in general. The system was originally developed for "Southwestern" North America where its adaptability has been well demonstrated. It is a natural world system. Incorporated are contributions of resource planners and users, plant geographers, zoogeographers, wildlife biologists and ecologists, all of which are in general usage today.

A digitized system facilitates overall land use classification, resource planning, inventory, and assessment, the interpretation of environmental uses and limitations, the delineation of recreational areas and wildlife habitats, and other activities of those concerned with natural resource enquiry. The system has proven especially useful for environmental analysis where the inventory, assessment, and comparison of environmental systems is desired or required by governmental, educationan, scientific, architectural, engineering, and other organizations. In short, the system is of particular use for those interested in and/or requiring classification of areas for resource management, for study, for acquisition and/or for preservation as "natural areas" throughout the world.

The digitation of hierarchy in the system makes it computer-compatible, for example as a system or subsystem for storing and retrieving general information and data within or parallel to an overall management system. This system, as applied to the southwestern United States, is currently in use in the RUNWILD Program being developed for field unit use on remote terminals, by Region 3 and the Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service. This system is similarly incorporated in the State of Arizona Resources Inventory System (ARIS). It is also currently used by industry in environmental analysis procedures, for example as required by the National Environmental Policy Act.

Also the use of a hierarchical sequence allows for flexibility in mapping of those complex communities where intensive levels of mapping would be impractical or needlessly time consuming. The hierarchical sequence allows for mapping at any scale; we have mapped various levels of the system at 1:1,000,000; 1:500,000; 1:250,000; 1:125,000; 1:62,500, and others.

An important advantage of a hierarchical system based on biotic criteria is the meaningful assignment of plant and animal habitats. This classification not only recognizes plant components within an assigned ecological distribution, it also tells the reader which wildlife species could be expected to be present. As an example the occurrence of nesting wood ducks (*Aix sponsa*) is expected in certain *temperate* swampforests, as opposed to *subtropical* swampforests expected to be the nesting habitat of black-bellied tree ducks (*Dendrocygna autumnalis*).

We present here examples of the system to the third level (formation-type) to illustrate its application on a world basis. Our fifth level (community) examples for North America are presented to illustrate adaptability and use of the classification system; they are not meant to be either a definitive or final classification. Examples of the use of the system to the sixth (association) level are given in previous publications relating to the North American Southwest (Lowe 1961, Brown and Lowe 1974a, 1974b).

A DIGITIZED HIERARCHY OF THE WORLD'S NATURAL ECOSYSTEMS

Where:

1,000 = Biogeographic (Continental) Realm
  1,100 = Vegetation-Environment
    1,110 = Formation Type
      1,111 = Climatic (Thermal) Zone
        1,111.1 = Regional Formation (Biome)
          1,111.11 = Community (Series of generic dominants)
            1,111.111 = Association (of specific dominants)
              1,111.1111 = Composition-structure

The number preceding the comma (e.g., 1,000) refers to the world's *biogeographic realms* (see Table 1). Origin and evolutionary history are recognized as being of primary importance in the determination and classification of natural ecosystems. The mappable reality of the world's biogeographic realms is, of course, interpretive in part because it is dependent on the criteria used. In those regions where the components of one realm merge gradually with those of another, and the assignment of biogeographic origin is difficult, we include such transitional areas (wide ecotones) in both realms. The following seven realms are adapted from Wallace (1876); see also Darlington (1957), Dansereau (1957), Walter (1973), and Dasmann (1974):

100 Nearctic

Continental North America exclusive of the tropics and most of the highland areas south of the Tropic of Cancer. We include those tropic-subtropic regions in and adjacent to the North American Southwest and the Caribbean.

200 Palaearctic

Eurasia exclusive of the tropics. Africa north of the Sahel.

Table 1. Summary for the Natural Vegetation of the World to the First Digit Level

Biogeographic Realm		Upland Vegetation	Wetland Vegetation
1,000	Nearctic	1,100	1,200
2,000	Palaearctic	2,100	2,200
3,000	Neotropical-Antarctican	3,100	3,200
4,000	Oriental	4,100	4,200
5,000	Ethiopian	5,100	5,200
6,000	Australian	6,100	6,200
7,000	Oceanic	7,100	7,200

300 Neotropical and Antarctican

Continental South America, Central America, and most of Mexico south of Tropic of Cancer. Antarctica.

400 Oriental

Southeast Asia, the Indian subcontinent. The Philippines, Indonesia, etc.

500 Ethiopian

Africa south of the Sahara, Malagasy and parts of the Arabian peninsula.

600 Australian

Australia and Tasmania.

700 Oceanic

Oceanic islands possessing a high degree of endemism.

FIRST LEVEL

The first digit after the comma (e.g., 1,100) refers to vegetation, both potential and/or existing. Included are all plant communities not cultivated, and that are presumed to be established naturally under existing climate and the cessation of artificially disruptive influences (Table 1).

All existing and potential natural vegetation (PNV) is classified as belonging to Uplands (1,100) or Wetlands (1,200) (Table 1) or Cultivated lands (1,300). The important adaptations inherent in the plants and animals of terrestrial (upland) ecosystems as opposed to hydric or aquatic (wetland) ecosystems is recognized by this dichotomy (see also Martin et al. 1953, and Ray 1975). Certain ecological systems having both upland and wetland characteristics and components (i.e., riparian forests) could properly be considered as belonging to both divisions.

SECOND LEVEL

Second digit after the comma (e.g., 1,110) refers to one of the following recognized ecological formations, which on a worldwide basis are the formation-types ("biome-types"). On continents, these are referred to as formations (Tables 2 and 3), which are vegetative responses (functions) to integrated environmental factors. Some plants are highly faculative and the same species may be a dominant in more than one formation. As an extreme example, mesquite (*Prosopis juliflora*) may be the dominant life-form in certain woodland, scrubland, desertland, and even forest and disclimax grassland formations.

Upland Formations

Tundra.

Communities existing in an environment so cold that moisture is unavailable during most of the year, precluding the establishment of

Table 2. Summary for the Natural UPLAND Vegetation of the World to the Second Level (Formation Type)

Biogeographic realm	Formation type					
	Tundra	Forest	Woodland	Scrubland	Grassland	Desertscrub
1,000 Nearctic	1,110	1,120	1,130	1,140	1,150	1,160
2,000 Palaearctic	2,110	2,120	2,130	2,140	2,150	2,160
3,000 Neotropical-Antarctican	3,110	3,120	3,130	3,140	3,150	3,160
4,000 Oriental	4,110	4,120	4,130	4,140	4,150	4,160
5,000 Ethiopian	5,110	5,120	5,130	5,140	5,150	5,160
6,000 Australian	6,110	6,120	6,130	6,140	6,150	6,160
7,000 Oceanic	7,110	7,120	7,130	7,140	7,150	7,160

Table 3. Summary for the Natural WETLAND Vegetation of the World to the Second Level (Formation Type)

Biogeographic realm	Formation type					
	Wet Tundra	Swampforest	Swampscrub	Marshland	Strand	Submergent
1,000 Nearctic	1,210	1,220	1,230	1,240	1,250	1,260
2,000 Palaearctic	2,210	2,220	2,230	2,240	2,250	2,260
3,000 Neotropical-Antarctican	3,210	3,220	3,230	3,240	3,250	3,260
4,000 Oriental	4,210	4,220	4,230	4,240	4,250	4,260
5,000 Ethiopian	5,210	5,220	5,230	5,240	5,250	5,260
6,000 Australian	6,210	6,220	6,230	6,240	6,250	6,260
7,000 Oceanic	7,210	7,220	7,230	7,240	7,250	7,260

trees, and in which the maximum development is that of perennial herbaceous plants, shrubs, lichens, and mosses, with grasses poorly represented or at least not dominant (Figure 1). The "holistic integrity" of a "Tundra" formation is not without serious question. Treated here, and within Wetland Formations, Tundra may also be composed of scrublands, marshlands (wet-tundra), and desertlands in an Arctic-Boreal climatic zone (Table 4).

Forest.

Communities comprised principally of trees potentially over 15 m in height, and frequently characterized by closed and/or multilayered canopies (Figure 2).

Woodland.

Communities dominated by trees with a mean potential height under 15 m, the canopy of which is usually open (sometimes very open) or interrupted and singularly layered (Figure 3). (The "savanna" formation (Dyksterhuis 1957 and others) is here recognized as an ecotone between woodland and grassland. Those areas in which the crowns of trees and shrubs normally cover less than approximately 15 percent of the ground space are classified as grasslands where grasses are actually or potentially dominant.)

Scrubland.

Communities dominated by sclerophyll or microphyll shrubs and/or small trees, usually evergreen or drought-deciduous and generally not exceeding 3 m in height, usually presenting a closed physiognomy or, if open, interspaced with other perennial vegetation (Figure 4).

Grassland.

Communities dominated actually or potentially by grasses (Figure 5).

Desertland.

Communities in an arid environment (usually less than 300 mm precipitation per annum) in which plants are separated by significant areas devoid of perennial vegetation (Figure 6).

Wetland Formations

Wet Tundra.

Aquatic communities existing in an environment so cold that available plant moisture is unavailable during most of the year, precluding the establishment of trees and all but a low herbaceous plant structure in hydric matrix (Figure 7).

Swampforest.

Aquatic communities possessing an overstory of trees potentially over 5 m in height, and frequently characterized by closed and/or multilayered canopies (Figure 8).

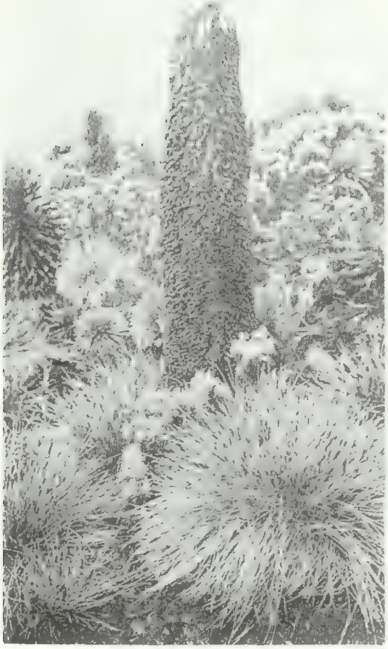


Figure 1. Tundra Formation Type (5,110), alpine community on the Ruwenzori Mountains in equatorial Africa (Time-Life Photo).

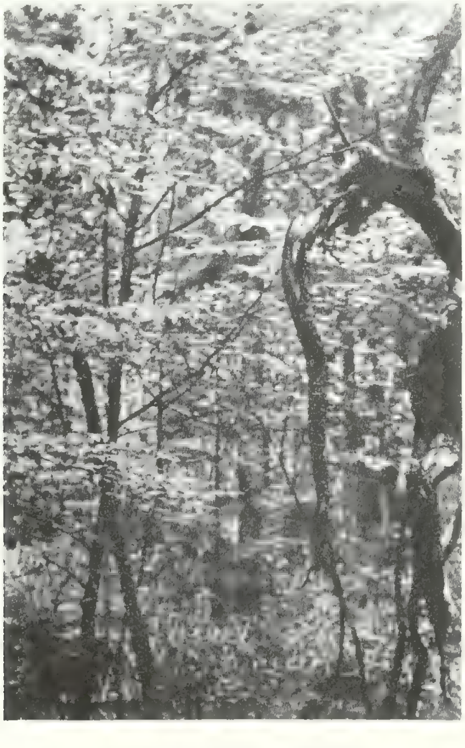


Figure 2. Forest Formation Type (2,120), Bialowieza Forest Reserve in eastern Europe (Time-Life Photo).

Table 4. Summary for the Natural UPLAND Vegetation of Nearctic and Adjacent Neotropical North America to the Third Level

Formation	Climatic (thermal) zone			
	Arctic-boreal	Cool temperate	Warm temperate	Subtropical tropical
1,110 Tundra	1,111			
1,120 Forest	1,121	1,122	1,123	1,124
1,130 Woodland	1,131	1,132	1,133	1,134
1,140 Scrubland	1,141	1,142	1,143	1,144
1,150 Grassland	1,151	1,152	1,153	1,154
1,160 Desertland	1,161	1,162	1,163	1,164

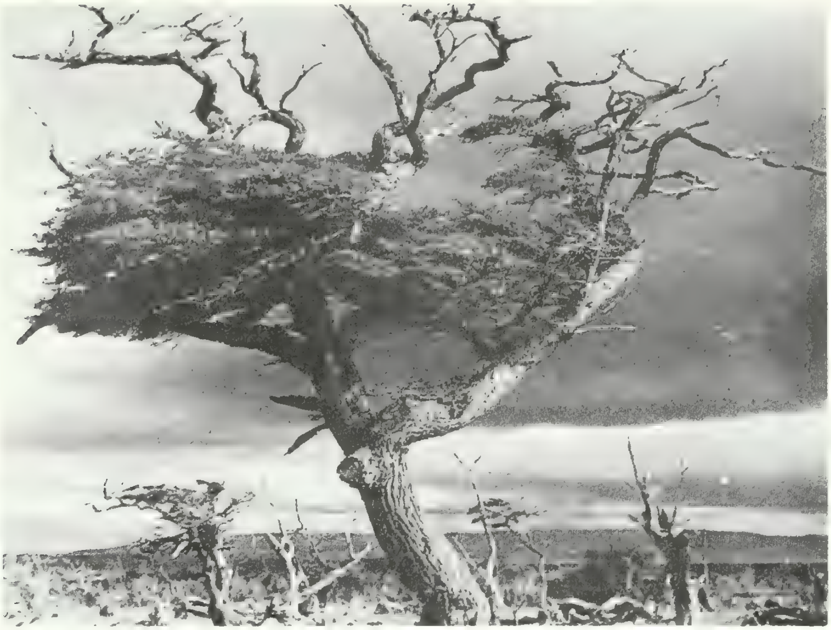


Figure 3. Woodland Formation Type (3,130), Nothofagus woodland in Patagonia, South America (Time-Life Photo).

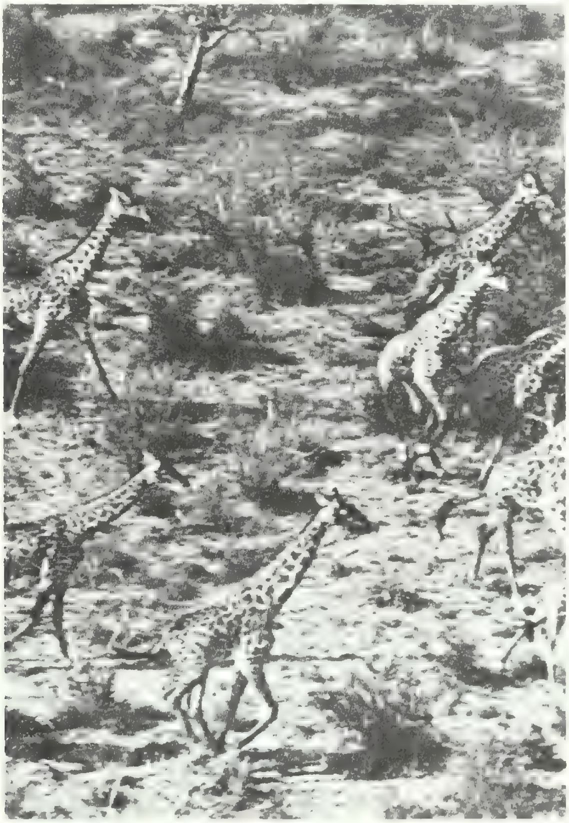


Figure 4. Scrubland Formation Type (5,140), thornscrub in central Africa (Time-Life Photo).

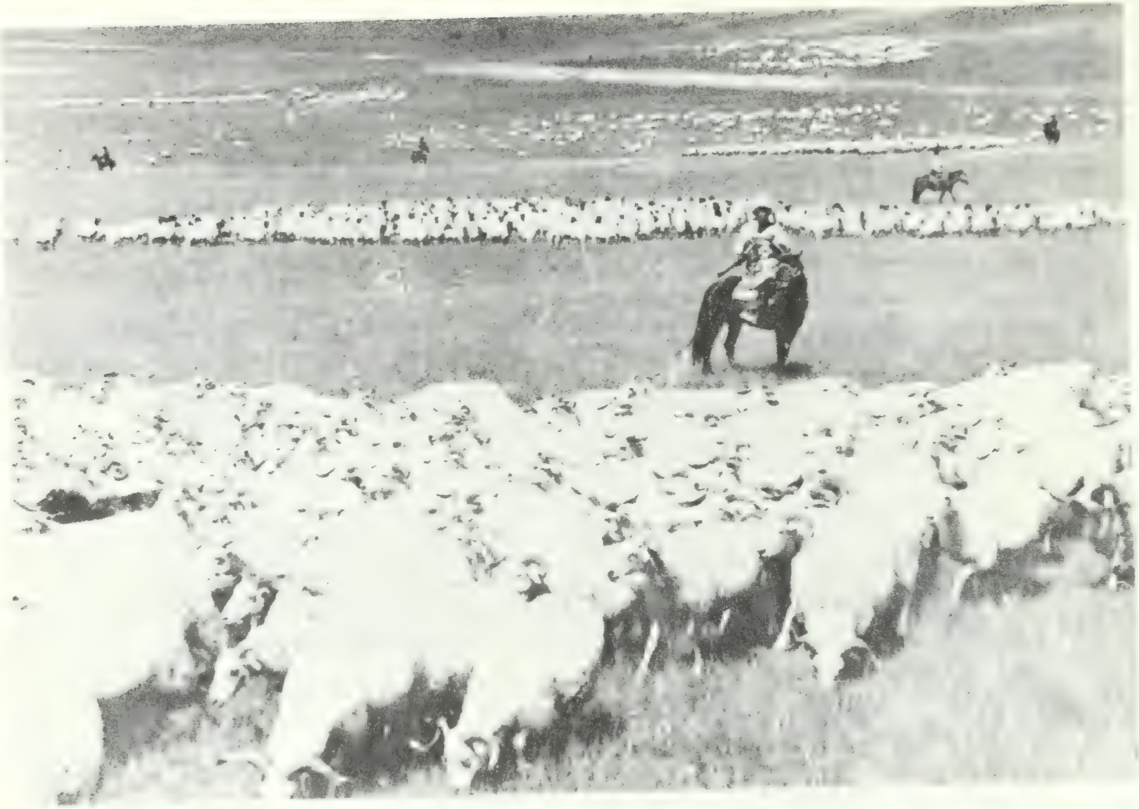


Figure 5. Grassland Formation Type (2,150), Asian shortgrass steppe (Time-Life Photo).

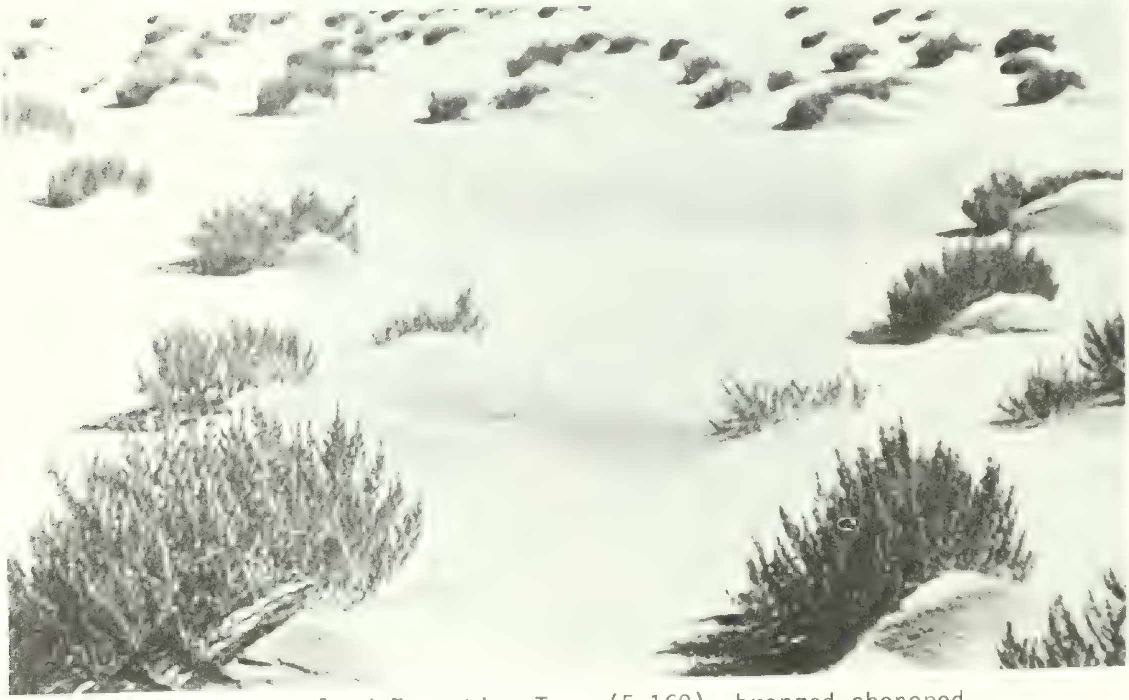


Figure 6. Desertland Formation Type (5,160), bronzed chenopod community in the Arabian Desert (Time-Life Photo).

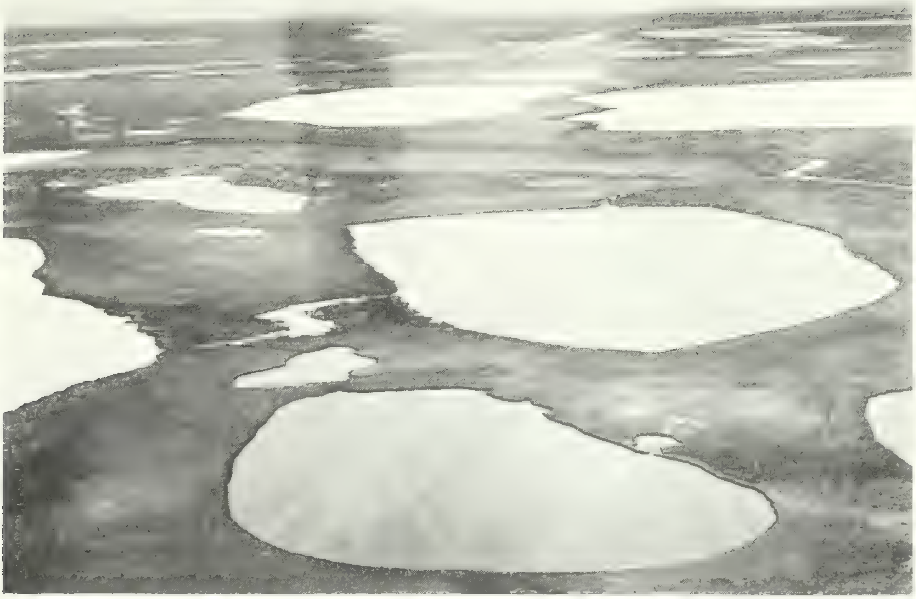


Figure 7. Wet Tundra (1,210), near Bristol Bay coast, Aviakchak Crater National Monument, Alaska (National Park Service Photo).

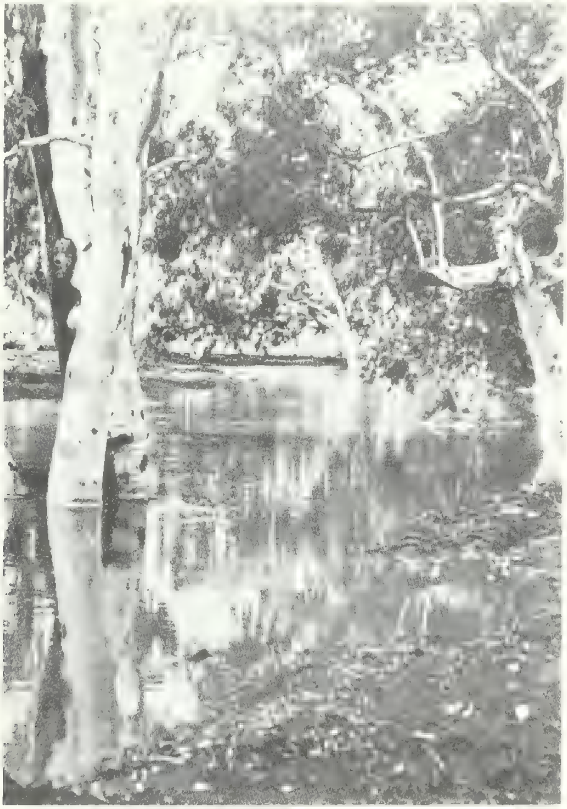


Figure 8. Swampforest (6,220), rivergum forest in Australia (Time-Life Photo).

Swampscrub.

Aquatic communities dominated by small trees and/or woody shrubs, generally under 5 m in height, often presenting a closed physiognomy (Figure 9).

Marshland.

Aquatic communities, in which the principal plant components are emergents, not trees, woody shrubs or non-halophytic grasses, and which normally have their basal portions annually, periodically, or continually submerged (Figure 10).

Strand.

Beach, lakeshore and river channel communities subject to infrequent but periodic submersion, wind driven waves and spray. Plants are separated by significant areas devoid of perennial vegetation (Figure 11).

Submergents.

Some uplands and wetlands are essentially without vegetation or are sparingly populated by simple organisms, e.g., dunes, lava flows, playas, sinks, etc. For purposes of classification those areas could be considered as belonging to a nonvegetated formation-type. Aquatic communities comprised entirely or almost entirely of plants lacking emergent structures (Figure 12).

THIRD LEVEL

Third digit beyond the comma (e.g., 1,111) refers to one of four world climatic zones (cf Walter 1973, Ray 1975) in which minimum temperature remains a major evolutionary control of and within the zonation and formation-types (Tables 4 and 5).

Arctic-Boreal (Antarctic-Austreal).

Characterized by lengthy periods of freezing temperatures, with the coldest month isotherm -3°C (Köppen 1931); growing season of short duration (generally less than 100 days), occasionally interrupted by nights of below freezing temperatures.

Cool Temperate.

Freezing temperatures of short duration although of frequent occurrence during winter months. Potential growing season generally from 100 to 200 days and confined to spring and summer seasons when freezing temperatures are infrequent or absent.

Warm Temperate.

Freezing temperatures of short duration but generally occurring every year during winter months. Potential growing season over 200 days with less than an average of 125-150 days being subject to temperature of 0°C or less.

Table 5. Summary for the Natural WETLAND Vegetation of Neartic and Adjacent Neotropical North American to the Third Level

Formation	Climatic (thermal) zone Arctic-boreal	 Cool temperate	 Warm temperate	 Subtropical tropical
1,210 Wet Tundra	1,211			
1,220 Forest[a]	1,221	1,222	1,223	1,224
1,230 Swamp-scrub	1,231	1,232	1,233	1,234
1,240 Marshland	1,241	1,242	1,243	1,244
1,250 Strand	1,251	1,252	1,253	1,254
1,260 Submergent	1,261	1,262	1,263	1,264

[a] Swamp forests, bog forests, and riparian forests.

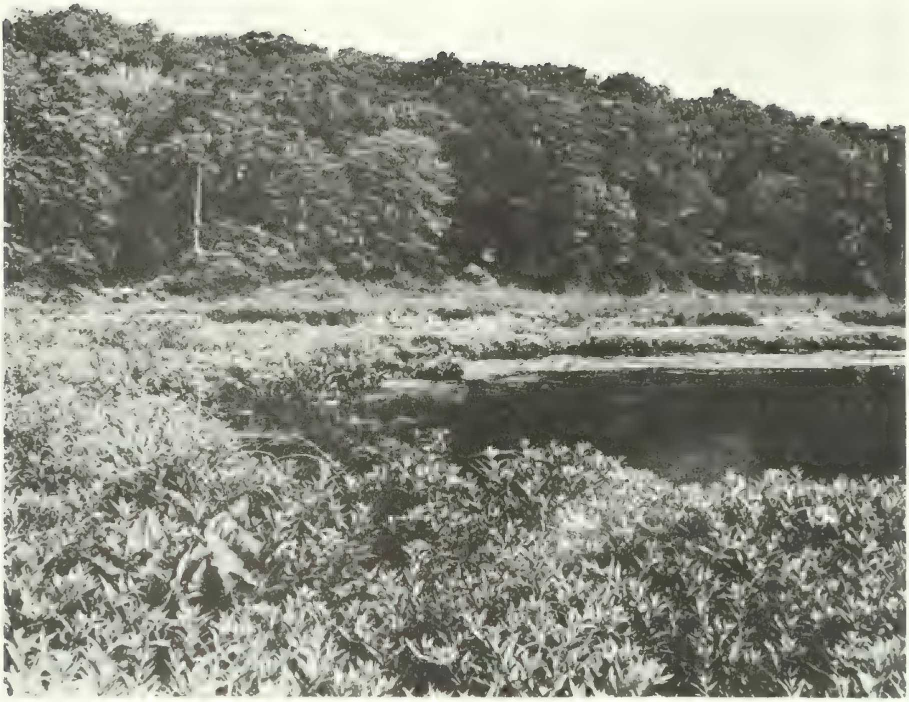


Figure 9. Swampscrub (1,230), water willow community in the New England area of North America, USA (U.S. Fish and Wildlife Service Photo).

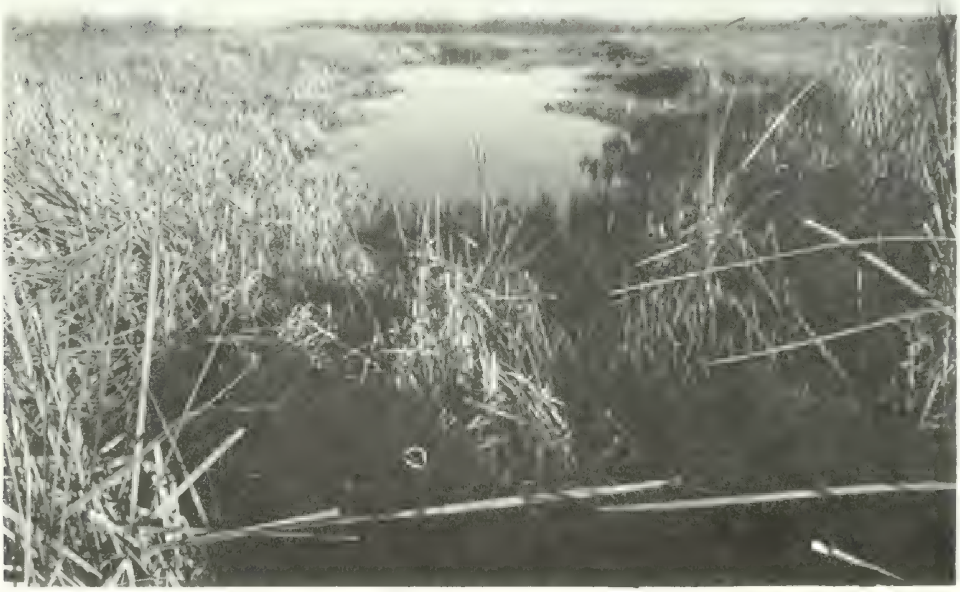


Figure 10. Marshland (1,240), freshwater cattail marsh on the Colorado River between Arizona and California, USA (Photo by Richard L. Todd).

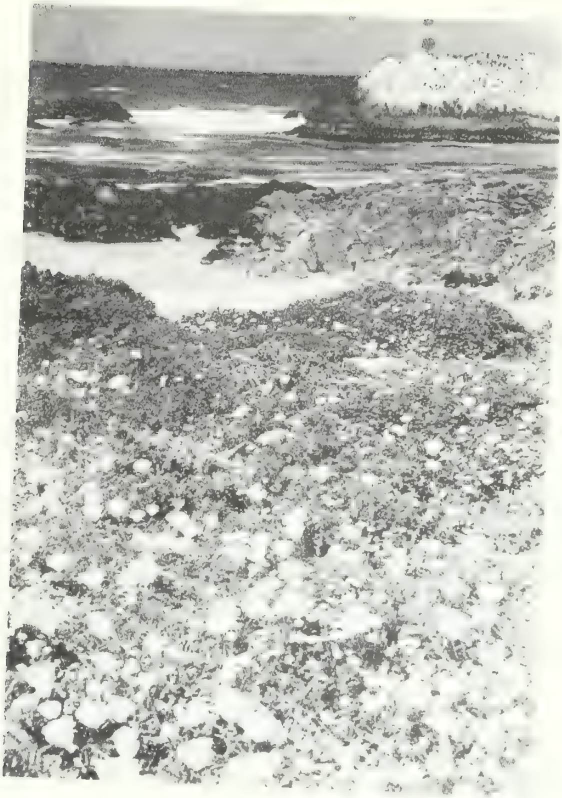


Figure 11. Strand (1,250), on the west coast of North America, USA (Time-Life Photo).

Figure 12. Submergent (1,260), kelp beds and sea otters off west coast of North America, USA (Sierra Club Photo).

FOURTH LEVEL

(e.g., 1,111.1) refers to subcontinental unit that is a *major biotic community* (=biome)--with a distinctive physiognomy--within a formation, centered in but not necessarily restricted to a biogeographic region or province (Figure 13). It is this and the fifth levels that have provided the most successful and useful mapping of states, provinces, republics, and continents. A partial summary of the biomes for Nearctic and adjacent Neotropical America is given in Tables 6 and 7.

FIFTH LEVEL

(e.g., 1,111.11) provides the principal plant-animal *communities* within the biomes, recognized and distinguished primarily on distinctive climax plant dominants. The diversity of tropical and sub-tropical climax dominants is inherently more complex than in boreal and temperate communities. The structure of fifth and sixth level communities will require interpretive revision and modification of the classification as field investigations accumulate. No attempt is made to complete this level of classification at this writing.

SIXTH LEVEL

(e.g., 1,111.111) refers to distinctive plant associations (and successional associes, constituted by single species that are termed consociations and successional consocies) based on the occurrence of particular dominants more or less local (or regional) in distribution. While we have demonstrated the applicability and usefulness of this level to regional areas, e.g., in the North American Southwest (Brown and Lowe 1973, 1974a, 1974b), the enormous numbers of sets precludes presentation here for the continental treatments in Tables 6 and 7. These may be added at length for regional studies with a,b,c sets.

SEVENTH LEVEL

(e.g., 1,111.1111) accommodates detailed measurements and assessment(s) of quantitative structure, composition, density, and other numerical determinations for dominant and other species. Implementation of this level in the system is designed for intensive studies for limited areas (e.g., Dick-Peddie and Moir 1970).

LITERATURE CITED

Anderson, J.R., 1971. Land use classification schemes. Photogramm. Eng. 37(4):379-387.

Anderson, J.R., E.E. Hardy, and J.T. Roach, 1972. A land use classification system for use with remote sensor data. Geol. Surv. Circ. 671. 15 pp.

Aubreville, A., 1958. Vegetation Map of Africa South of the Tropic of Cancer. Oxford Univ. Press, Oxford. Map.

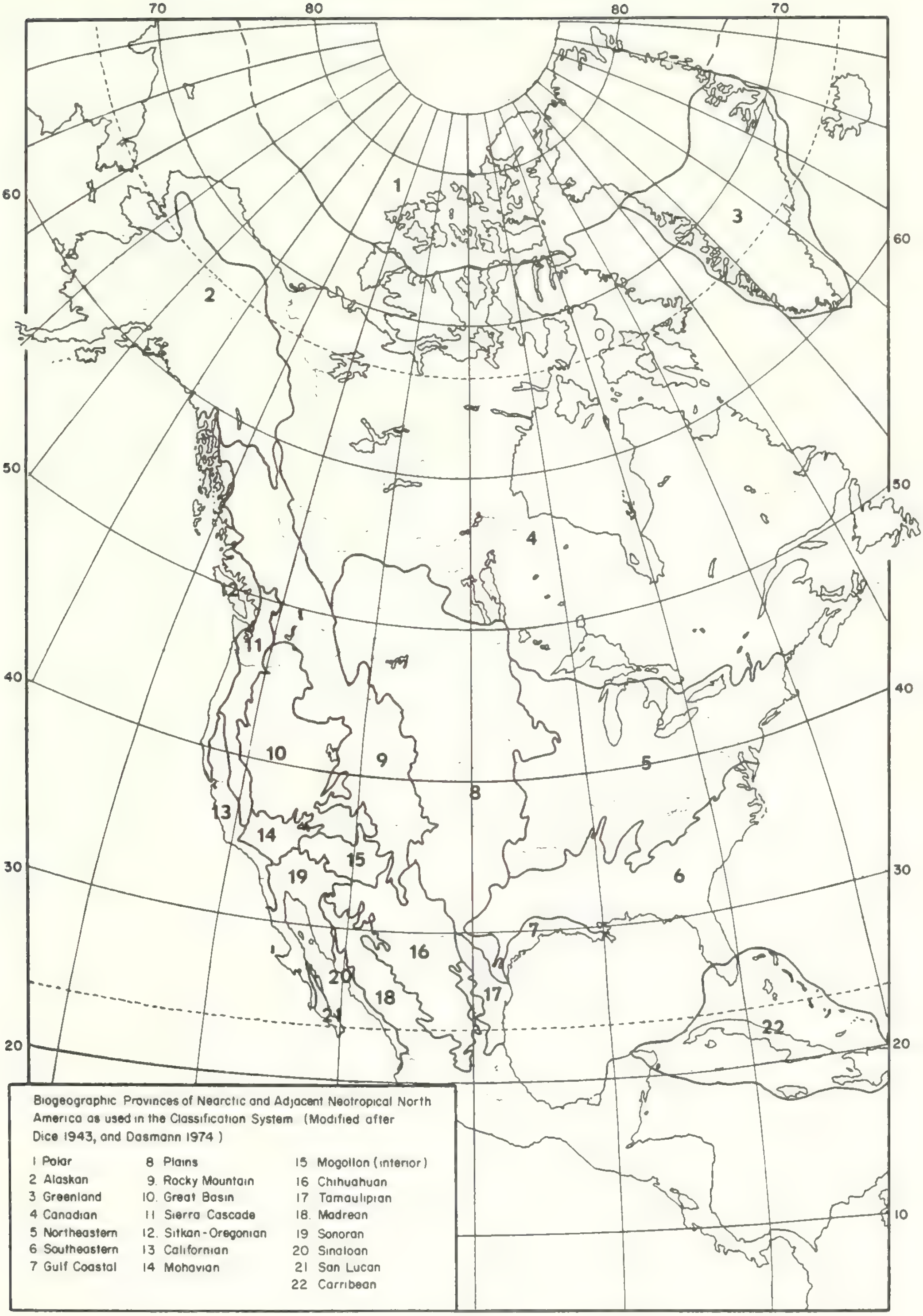


Figure 13. Biogeographic provinces of Nearctic and adjacent Neotropical North America as used in the classification system.

Table 6. Example UPLAND Biotic Communities (Fourth Level) of Nearctic and Adjacent Neotropical North America with Fifth Level (Community) Examples

---

1,100 Nearctic Upland Vegetation

1,110 Tundra Formation

1,111 Arctic Tundra

1,111.1 Polar (High Arctic) Tundra

1,111.11 Sedge-Moss (Meadow) Communities[a]

1,000.12 Cushion Plant-Lichen Communities

1,111.2 Alaskan (Low Arctic) Coastal Tundra

111.21[b] Sedge-Grass-Moss Communities[a]

111.22 Cottongrass (Tussock) Communities

111.23 Heath-Avens Communities

111.3 Canadian (Barren Ground = Low Arctic) Tundra

111.31 Heath-Lichen Communities[a]

111.4 Arctic Alpine Tundra

111.41 Heath-Lichen Communities[a]

111.5 Sierran-Cascadean Alpine Tundra

111.51 Cushion Plant Communities[a]

111.6 Rocky Mountain Alpine Tundra

111.61 Lichen-Moss Communities[a]

111.7 Adirondack-Appalachian Alpine Tundra

111.71 Lichen-Moss Communities[a]

120 Forest Formation

121 Boreal Forest

121.1 Canadian Subarctic Conifer Forest

121.11 White Spruce-Balsam Fir Communities[a]

121.12 Black Spruce Communities[a]

121.2 Appalachian Subalpine Conifer Forest

    - 121.21 Red Spruce - Balsam Fir
  - 121.3 Rocky Mountain Subalpine Conifer Forest
    - 121.31 Bristlecone Pine - Limber Pine Communities[a]
    - 121.32 Engelmann Spruce-Alpine Fir Communities[a]
  - 121.4 Sierran-Cascadean Subalpine Conifer Forest
    - 121.41 Whitebark Pine Communities[a]
  - 121.5 Madrean Subalpine Conifer Forest
    - 121.51 Pine-Religious Fir Communities[a]
- 122 Cool Temperate Forest
  - 122.1 Northeastern Deciduous Forest
    - 122.11 Oak-Hickory Communities[a]
    - 122.12 Oak-Chestnut Communities
    - 122.13 Beach-Maple Communities
    - 122.14 Oak-Pine Communities
    - 122.15 Maple-Basswood Communities
    - 122.16 Hemlock-White Pine-Hardwood Communities
  - 122.2 Pacific Coastal (Oregonian) Conifer Forest
    - 122.21 Coast Redwood Communities[a]
    - 122.22 Douglas-fir Communities
    - 122.23 Hemlock-Sitka Spruce Communities
  - 122.3 Rocky Mountain Montane Conifer Forest
    - 122.31 Douglas-fir Communities[a]
    - 122.32 Ponderosa Pine Communities
  - 122.4 Sierran-Cascadean Conifer Forest
    - 122.41 Fir Communities[a]
  - 122.5 Madrean Montane Conifer Forest

Table 6. (Continued)

---

123 Warm Temperate Forest

- 123.1 Southeastern Mixed Deciduous and Evergreen Forest
  - 123.11 Pine Communities[a]
  - 123.12 Mixed Mesophytic Communities
  - 123.13 Mixed Hardwood (Hammock) Communities
- 123.2 Southwestern (Riparian) Deciduous Forest[c]
  - 123.21 Mixed Broadleaf Communities[a]
  - 123.22 Cottonwood-Willow Communities
- 123.3 California Mixed Evergreen Forest
  - 123.31 Mixed Mesophytic Communities[a]
- 123.4 Relict Conifer Forest
  - 123.41 Closed-cone Pine Communities[a]
  - 123.42 Cypress Communities

124 Subtropical-Tropical Forest

- 124.1 Sonoran Oasis Forest
  - 124.11 Fan Palm Communities[a]
- 124.2 Sinaloan Deciduous Forest
  - 124.21 Mixed Short-tree Communities[a]
- 124.3 Sinaloan Riparian Evergreen Forest
  - 124.31 Mixed Broadleaf Communities[a]
  - 124.32 Palm Communities
- 124.4 Tamaulipan Semi-Deciduous Forest
  - 124.41 Mixed Short-tree Communities[a]
- 124.5 Tamaulipan (Riparian) Evergreen Forest
  - 124.51 Mixed Broadleaf Communities[a]
  - 124.52 Palm Communities

Table 6. (Continued)

    - 124.6 Caribbean Evergreen Forest
      - 124.61 Pine Communities[a]
      - 124.62 Tabebuia-Gallo Communities
    - 124.7 Caribbean Montane Rain Forest
      - 124.71 Palm Communities[a]
      - 124.72 Tabenuco-Palocolorado Communities
    - 124.8 Caribbean Cloud Forest
      - 124.81 Ocotea-Roble de Sierra Communities[a]
    - 124.9 Caribbean Deciduous Forest
      - 124.91 Mixed Short Tree Communities[a]
- 130 Woodland Formation
  - 131 Arctic-Boreal Woodland
    - 131.1 Subpolar Conifer Woodland (North America Taiga)
      - 131.11 Spruce-Tamarack-Lichen Communities[a]
      - 131.12 Birch-Lichen Communities
    - 131.2 Rocky Mountain Subalpine Conifer Woodland
      - 131.21 Limber Pine Communities
  - 132 Cool Temperate Woodland
    - 132.1 Great Basin Conifer Woodland
      - 132.11 Pinyon-Juniper Communities[a]
  - 133 Warm Temperate Woodland
    - 133.1 Californian Evergreen Woodland
      - 133.11 Encinal (Oak) Communities[a]
      - 133.12 Oak-Pine (Foothill) Communities
    - 133.2 Madrean Evergreen Woodland
      - 133.21 Encinal (Oak) Communities[a]

- 133.22 Oak-Pine Communities
- 134 Tropical-Subtropical Woodland
  - 134.1 Subtropical Woodland
    - 134.11 Mesquite Communities[a]
- 140 Scrubland Formation
  - 141 Arctic-Boreal Scrubland
    - 141.1 Alaskan (Low Arctic) Coastal Scrub
      - 141.11 Crowberry Communities[a]
      - 141.12 Birch-Willow Communities
    - 141.2 Canadian (Low Arctic, Barren Ground) Subpolar Scrub
      - 141.21 Birch-Willow Communities[a]
      - 141.22 Alder Communities
    - 141.3 Alaskan Alpine Scrub
      - 141.31 Willow-Birch Communities[a]
    - 141.4 Sierran-Cascadean Alpine Scrub
      - 141.41 Pine Elfinwood Communities[a]
    - 141.5 Rocky Mountain Alpine Scrub
      - 141.51 Willow Communities[a]
      - 141.52 Spruce Elfinwood Communities
    - 141.6 Adirondack-Appalachian Alpine Scrub
      - 141.61 Hobblebush Communities[a]
  - 142 Cool Temperate Scrubland
    - 142.1 Great Basin Montane Scrub
      - 142.11 Oak-Scrub Communities[a]
      - 142.12 Mountain Mahogany Communities
      - 142.13 Maple Communities

Table 6. (Continued)

    142.14 Serviceberry Communities
    142.15 Bitterbrush Communities
  142.2 Sierran-Cascadean Montane Scrub
    142.21 Manzanita Communities[a]
  142.3 Plains Deciduous Scrub
    142.31 Oak-Scrub Communities[a]
    142.32 Sumac Communities
    142.33 Mixed Deciduous Communities
  142.4 Rocky Mountain (Riparian) Deciduous Scrub
    142.41 Willow-Dogwood Communities[a]
143 Warm Temperate Scrubland
  143.1 California Coastal Sagescrub
    143.11 Sage Communities[a]
    143.12 Mixed Scrub Communities
  143.2 Californian Coastal Chaparral
    143.21 Ribbonwood Communities[a]
    143.22 Scrub Oak Communities
    143.23 Manzanita Communities
    143.24 Mixed Evergreen Sclerophyll Communities
  143.3 Interior Chaparral
    143.31 Scrub Oak Communities[a]
    143.32 Manzanita Communities
    143.33 Mixed Evergreen Sclerophyll Communities
  143.4 Eastern Maritime Scrub
    143.41 Scrub Oak Communities[a]

Table 6. (Continued)

- 143.5 Southwestern Riparian Scrub
  - 143.51 Broom Communities[a]
  - 143.52 Saltcedar Communities
- 144 Tropical-Subtropical Scrubland
  - 144.1 Sinaloan Thornscrub
    - 144.11 Mixed Deciduous Communities[a]
  - 144.2 Tamaulipan Thornscrub
    - 144.21 Mixed Deciduous Communities[a]
  - 144.3 Caribbean Thornscrub
    - 144.31 Mixed Deciduous Communities[a]
  - 144.4 Sonoran Riparian Scrub
    - 144.41 Mixed Scrib Communities[a]
    - 144.42 Arrowweed Communities
    - 144.43 Saltcedar Communities
- 150 Grassland Formation
  - 151 Arctic-Boreal Grassland
    - 151.1 Alaskan (Low Arctic) Coastal Grassland
      - 151.11 Cottongrass Communities[a]
    - 151.2 Canadian (Low Arctic) Grassland
    - 151.3 Rocky Mountain Subalpine Grassland
      - 151.31 Bunchgrass Communities[a]
    - 151.4 Sierran-Cascadean Subalpine Grassland
      - 151.41 Bunchgrass Communities[a]
    - 151.5 Appalachian Subalpine (Balds) Grassland
      - 151.51 Oatgrass-Herb Communities[a]
  - 152 Cool Temperate Grassland

Table 6. (Continued)

- 152.1 Plains Grassland
  - 152.11 Bluestem Communities[a]
  - 152.12 Grama Communities
- 152.2 Great Basin Shrub-Grassland
  - 152.21 Wheatgrass Communities[a]
  - 152.22 Mixed Bunchgrass Communities
  - 152.23 Mixed Scrub-Grass Communities
- 152.3 Oregonian Grassland
  - 152.31 Mixed Bunchgrass Communities[a]
- 152.4 Rocky Mountain Montane Grassland
  - 152.41 Mixed Meadow Communities[a]
- 152.5 Sierran-Cascadean Montane Grassland
  - 152.51 Mixed Meadow Communities[a]

153 Warm Temperate Grassland

- 153.1 California Valley Grassland
  - 153.11 Annual Disclimax Communities[a]
- 153.2 Chihuahuan Scrub-Grassland (Semidesert Grassland)
  - 153.21 Grama Grass-Scrub Communities
  - 153.22 Tobosa Grass-Scrub Communities

154 Tropical-Subtropical Grassland

- 154.1 Gulf Coastal Grassland
  - 154.11 Beardgrass Communities[a]
- 162.1 Great Basin Desertscrub
  - 162.11 Sagebrush Communities[a]
  - 162.12 Shadscale Communities
  - 162.13 Rabbitbrush Communities

Table 6. (Concluded)

- 163 Warm Temperate Desertland
  - 163.1 Mohave Desertscrub
    - 163.11 Creosotebush Communities
  - 163.2 Chihuahuan Desertscrub
    - 163.21 Creosotebush Communities[a]
- 164 Tropical-Subtropical Desertland
  - 164.1 Sonoran Desertscrub
    - 164.11 Creosotebush-Bursage (Lower Colorado Valley) Communities[a]
    - 164.12 Paloverde-Cacti (Arizona Upland) Communities
    - 164.13 Ironwood-Brittlebush (Plains of Sonora) Communities
    - 164.14 Copal-Torote (Central Gulf Coast) Communities
    - 164.15 Agave-Bursage (Vizcaino) Communities
    - 164.16 Paloblanco-Agria (Magdalena) Communities
    - 164.17 Saltbush Communities
    - 164.18 Canotia-Creosotebush Communities

---

[a] Examples only.

[b] The first "1" (Nearctic Realm) is understood; it is dropped for convenience only, from this point onward.

[c] Division may be warranted; e.g., California Riparian Deciduous Forest, and Interior (Mogollon) Riparian Deciduous Forest.

Table 7. Third Level WETLANDS of Nearctic and Adjacent Neotropical North America. Fourth (Biome) and Fifth (Community) Level Examples are Given for the "Northeast" and "Southwest" as Adapted from Golet and Larson (1974) and Brown and Lowe (1974a)

- 1,200 Nearctic Wetland Vegetation
  - 1,210 Wet Tundra Formation
    - 1,211 Arctic Wet Tundra
  - 220 Forest Formation
    - 221 Boreal Forest
      - 221.1 Canadian Swampforest
      - 221.2 Black Spruce-Tamarack Communities[b]
    - 222 Cool Temperate Forest
      - 222.1 Northeastern Bog, Swamp, and Riparian Forests
        - 222.11 White Cedar Communities[b]
        - 222.12 Ash-Maple Communities[b]
      - 222.2 Rocky Mountain Riparian Deciduous Forest
        - 222.21 Cottonwood-Willow Communities[b]
        - 222.22 Mixed Broadleaf Communities[b]
    - 223 Warm Temperate Forest
      - 223.2 Southwestern Riparian Deciduous Forest
        - 223.21 Cottonwood-Willow Communities[b]
        - 223.22 Mixed Broadleaf Communities[b]
    - 224 Tropic-Subtropic Forest
      - 224.1 Sinaloan Swamp and Riparian Forest
        - 224.11 Mixed Evergreen Communities[b]
  - 230 Swampscrub Formation
    - 231 Arctic-Boreal Swampscrub
      - 231.3 Canadian Swampscrub
        - 231.31 Leatherleaf Communities[b]

Table 7. (Continued)

- 232 Cool Temperate Swampscrub
  - 232.1 Northeastern Deciduous Swamp (and Riparian) Scrub
    - 232.11 Sweet Gale Communities[b]
    - 232.12 Buttonbush-Willow Communities[b]
    - 232.13 Waterwillow Communities
- 233 Warm Temperate Swampscrub
  - 233.1 Southwestern Freshwater Swamp and Riparian Scrub
    - 233.11 Mixed Evergreen Communities[b]
    - 233.12 Saltcedar Disclimax Communities
- 234 Tropic-Subtropical Swampscrub
  - 234.1 Sonoran Riparian Scrub and Swampscrub
    - 234.11 Saltcedar Disclimax Communities[b]
  - 234.2 Sinaloan Maritime Swampscrub
    - 234.21 Mangrove Communities[b]

240 Marshland Formation

- 241 Arctic-Boreal Marshland
- 242 Cool Temperate Marshland
  - 242.1 Northeastern Freshwater Marshland
    - 242.11 Sedge Communities[b]
    - 242.12 Rush Communities[b]
    - 242.13 Bur-reed Communities[b]
    - 242.14 Cattail Communities[b]
    - 242.15 Arrow arum Communities[b]
    - 242.16 Water Lily Communities[b]
    - 242.17 Reed canary grass Communities[b]
  - 242.2 Northeastern Maritime Marshland

- 242.3 Rocky Mountain Freshwater Marshland
  - 242.31 Sedge Communities[b]
  - 242.32 Rush Communities[b]
  - 242.33 Bullrush Communities[b]
- 243 Warm Temperate Marshland
  - 243.1 Southwestern Freshwater Marshland
    - 243.11 Cattail Communities[b]
  - 243.2 Chihuahuan Interior Marshland
    - 243.21 Saltgrass Communities[b]
  - 243.3 California Maritime Marshland
    - 243.31 Pickleweed-Iodinebush Communities
- 244 Tropic-Subtropic Marshland
  - 244.1 Sonoran Freshwater Marshland
    - 244.11 Cattail Communities[b]
  - 244.2 Sonoran Maritime Marshland
    - 244.21 Saltscrub Communities[b]

250 Strand Formation

- 251 Arctic-Boreal Strand
- 252 Cool Temperate Strand
  - 252.1 Northeastern Lake Strand
  - 252.2 Northeastern Maritime Strand
- 253 Warm Temperate Strand
  - 253.1 California Coastal Strand
- 254 Tropic-Subtropic Strand
  - 254.1 Sonoran Coastal Strand

Table 7. (Concluded)

- 260 Submergent Vegetation
  - 261 Arctic-Boreal Submergent
    - 261.1 Canadian Freshwater Submergents[b]
    - 261.2 Rocky Mountain Subalpine Submergents[b]
  - 262 Cool Temperate Submergents
    - 262.1 Northeastern Freshwater Submergents[b]
    - 262.2 Rocky Mountain Montane Submergents
  - 263 Warm Temperate Submergents
    - 263.1 California Marine Submergents[b]
  - 264 Tropic-Subtropic Submergents
    - 264.1 Sinaloan Marine Submergents[b]

---

[a] One or more examples only are given for the fifth level.

[b] Note that the first "1" (in front of comma, and representing the Nearctic Realm) is understood, and dropped for tabular convenience only, from this point onward.

LITERATURE CITED (Continued)

Braun-Blanquet, J., 1932. Pflanzensoziologie. 3rd ed. Springer-Verlag, Berlin. 439 pp.

Braun-Blanquet, J., 1964. Plant Sociology: The Study of Plant Communities. (Transl., G.D. Fuller and H.S. Conrad) McGraw-Hill Book Co., Inc., New York. 865 pp.

Brown, D.E., and C.H. Lowe, 1973. A Proposed Classification for Natural and Potential Vegetation in the Southwest with Particular Reference to Arizona. Ariz. Game & Fish Dept., Fed. Aid Proj. Rep. W-53-R-22-WP-4-J1. 26 pp.

Brown, D.E., and C.H. Lowe, 1974a. A digitized computer-compatible classification for natural and potential vegetation in the Southwest with particular reference to Arizona. J. Ariz. Acad. Sci. 9 Suppl. 2:1-11.

Brown, D.E., and C.H. Lowe, 1974b. The Arizona system for natural and potential vegetation--illustrated summary through the fifth digit for the North American Southwest. J. Ariz. Acad. Sci. 9 Suppl. 3:31-56.

Comision Tecnico Consultiva para la Determinacion Regional de los Coeficientes de Agostadero, 1974. Coeficientes de Agostadero de la Republica Mexicana, Estado de Sonora Secretaria de Agricultura y Ganaderia, Mexico D.F. 133 pp.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. Laroe. Interim classification of wetlands and aquatic habitats of the United States, In proceedings of the National Wetland Classification and Inventory Workshop. U.S. Fish and Wildlife Serv., Addendum. 110 pp.

Dansereau, P., 1957. Biogeography. Ronald Press, New York. 394 pp.

Darlington, P.J., Jr., 1957. Zoogeography. John Wiley and Sons, Inc., New York. 675 pp.

Dasmann, R.S., 1972. Towards a system for classifying natural regions of the world and their representation by National Parks and Reserves. Biol. Cons. 4:247-255.

Dasmann, R.S., 1974. Biotic Provinces of the World--Further Development of a System for Defining and Classifying Natural Regions for Purposes of Conservation. Intl. Union Conserv. Nat., Occas. Paper 9. 57 pp.

Daubenmire, R.F., 1952. Forest vegetation of northern Idaho and adjacent Washington and its bearing on concepts of vegetation classification. Ecol. Monog. 22:301-330.

Dick-Peddie, W.A., and W.H. Moir, 1970. Vegetation of the Organ Mountains, New Mexico. Colorado State Univ. Range Sci. Dept., Sci. Ser. 4:1-28.

Dyksterhuis, E.J., 1957. The savannah concept and its use. Ecology 38:435-442.

Ellenberg, H., and D. Mueller-Dombois, 1967. Tentative physiognomic-ecological classification of plant formations of the earth. Berlin Geobotan. Inst. 37:21-55.

Fittkau, E.J., 1969. The fauna of South America, In Biogeography and Ecology in South America. W. Junk, The Hague. 2 vol.

Fosberg, F.R., 1961. A classification of vegetation for general purposes. Trop. Ecol. 2:1-28.

Flores, M.G., L.J. Jimenez, S.X. Madrigal, R.F. Moncayo, and T.F. Takaki, 1971. Tipos de Vegetacion de la Republic Mexicana. Subsecretaria de Planeacion Direccion General de Estudios, Direccion de Agrologia, SRH. Mexico, D.F. 59 pp.

Garrison, G.A., A.J. Bjugstad, D.A. Duncan, M.E. Lewis and D.R. Smith, 1974. Vegetation and Environmental Features of Forest and Range Ecosystems. U.S.D.A., For. Serv., Agric. Handb. 475. 68 pp.

Gaussen, H., 1953. A proposed ecological vegetation map. Surv. and Mapping 13:168-173.

Gaussen, H., 1955. Les Divisions Ecologiques du Monde. Paris Centre Natimal de la Recherche Scientifique, 59th Intl. Colloquim, 1954.

Golet, F.C., and J.S. Larson, 1974. Classification of Freshwater Wetlands in the Glaciated Northeast. Bur. Sport Fish. and Wildl., Res. Publ. 116. 56 pp.

International Union for Conservation of Nature and Natural Resources, 1973. A Working System for Classification of World Vegetation. IUCN Occas. Paper 5. 21 pp.

IUCN, 1974. Biotic Provinces of the World--Further Development of a System for Defining and Classifying Natural Regions for Purposes of Conservation. Occas. Pap. No. 9. pp. 1-57.

Köppen, W., 1931. Gundriss der klimakunde. Walter de Gruyter Co., Berlin. 361 pp.

Krajina, V.J., 1965. Biogeoclimatic zones and biogeocoenoses of British Columbia In Ecology of Western North America. Univ. British Columbia, Dept. Botany, Vancouver.

Küchler, A.W., 1967. Vegetation Mapping. Ronald Press, New York. 472 pp.

Layser, E.F., 1974. Vegetative classification: its application to forestry in the northern Rocky Mountains. J. For. 72:354-357.

Lowe, C.H., 1961. Biotic communities in the sub-Mogollon region of the inland Southwest. J. Ariz. Acad. Sci. 2:40-49.

Martin, A.C., N. Hotchkiss, F.M. Uhler, and W.S. Bourn, 1953. Classification of Wetlands of the United States. U.S. Fish and Wildl. Serv., Spec. Sci. Rep. Wildl. 20. 14 pp.

Pfister, R.D., 1975. Land capability assessment by habitat types, In America's Renewable Resource Potential--the Turning Point. Proc. Natl. Conv. Soc. Am. For.

Ray, G.C., 1975. A Preliminary Classification of Coastal and Marine Environments. IUCN Occas. Paper 14. 26 pp.

Society of American Foresters, 1954. Forest Cover Types of North America (Exclusive of Mexico). Soc. Am. For., Washington, D.C. Map.

Stewart, R.E., and H.A. Kantrud, 1971. Classification of Natural Ponds and Lakes in the Glaciated Prairie Region. Bur. Sport Fish. and Wildl., Res. Publ. 92. 57 pp.

USDA Forest Service, 1977. MODIFIED ECOCLASS--A Method for Classifying Ecosystems for the Rocky Mountain and Southwestern Regions. Rocky Mountain and Southwest Region and Rocky Mountain For. and Range Exp. Stn., Ad Hoc Committee. 112 pp.

Wallace, A.R., 1876. The Geographical Distribution of Animals, with a Study of the Relations of Living and Extinct Faunas and as Elucidating the Past Changes of the Earth's Surface. MacMillan and Co., London. 2 vol.

Walter, H., 1973. Vegetation of the Earth in Relation to Climate and the Ecophysiological Conditions. English Univ. Press. Ltd., London. 237 pp.

Wieslander, A.E., 1935. A vegetation type map of California. Madrono 3:140-144.

EVALUATION OF HABITAT QUALITY IN WYOMING TROUT STREAMS

N. Allen Binns
Senior Aquatic Habitat Biologist
Wyoming Game and Fish Department
Box 342
Lander, Wyoming 82520

Abstract: In response to Federal requirements for non-monetary evaluation of water development projects, a rating system was developed to quantify habitat quality in trout streams in the Rocky Mountains. Twenty-one environmental attributes were measured at 20 study sites in Wyoming and the relationship between attributes and trout standing crop was explored by multiple regression analysis. Ten attributes were significantly related to trout biomass and were used to develop a predictive model of habitat quality, the Habitat Quality Index (HQI). Attributes used in the HQI were: late summer stream flows, annual stream flow variation, stream velocity, cover, stream width, streambank stability, fish food abundance and diversity, nitrate concentration, and maximum summer stream temperature.

The multiple regression analysis indicated that HQI scores were highly related to trout production (R = 0.98), which suggests that the HQI method is a realistic measure of habitat quality in trout streams.

A trout Habitat Unit was defined as the amount of habitat quality required to produce an increase, in the trout standing crop, of one unit of trout biomass.

Using the HQI and Ryder's Morphoedaphic Index, as well as the concepts of Ecological Completeness and Habitat Integrity, a computation procedure was developed for calculation of habitat loss or gain for trout streams located within the impoundment area of proposed reservoirs.

In response to Federal requirements for non-monetary evaluation of water development projects, as promulgated by Water Resources Council (1973), a rating system has been developed to quantify habitat quality in trout streams. Criteria developed from the literature were used to describe 21 environmental attributes believed to be important determinants of habitat quality in trout streams of the Rocky Mountains. Attribute measurements were collected at 20 study sites on a wide variety of Wyoming streams and the rating system was used to evaluate habitat quality at each study site. Estimates of standing crop of trout were limited to work done using electrofishing gear and either the Peterson or the DeLury population estimation technique.

The relationship between stream habitat attributes and standing crop of trout was examined by multiple regression analysis. Nine of the attributes were significant at the 95 percent level and three others (temperature, turbidity, and bank vegetation) were almost significant at that level (Table 1). After further statistical testing indicated that only the temperature attribute improved model performance, a predictive model of habitat quality, the Habitat Index (HQI), was developed from the 10 attributes best related to trout standing crop (Appendix I).

TABLE 1. Stream Habitat Attributes Selected for the Habitat Quality Index

Attribute	Model symbol	Correlation coefficient
Primary factors		
Critical period stream flows	(X_1)	0.36[a]
Annual stream flow variation	(X_2)	0.80[b]
Maximum summer stream temperature	(X_3)	0.28
Secondary factors		
Water velocity	(S_1)	0.38[a]
Cover	(S_2)	0.55[b]
Stream width	(S_3)	0.38[a]
Food abundance	(S_4)	0.57[b]
Food diversity	(S_5)	0.57[b]
Nitrates	(S_6)	0.69[b]
Stream bank stability	(S_7)	0.45[a]

[a] Significantly different from zero at the 95 percent confidence level.

[b] Significantly different from zero at the 99 percent confidence level.

The model selected is given by the following expression:

$$HQI = \log(Y + 1.0) = (-1.18257) + (0.97329)\log(1.0 + X_1) + (1.65824)\log(1.0 + X_2) + (1.44821)\log(1.0 + X_3) + (0.30762)\log(1.0 + P)$$

Where,

Y = standing crop of trout

X_1 = critical period stream flow

X_2 = annual stream flow variation

X_3 = maximum summer stream temperature

P = the product of the seven secondary factor ratings
= $(S_1)\ (S_2)\ (S_3)\ (S_4)\ (S_5)\ (S_6)\ (S_7)$

The above model was used to compute HQI scores for the test streams and the results were plotted against estimates of standing crop of trout from the same streams (Figure 1). Examples of HQI calculation are given in Appendices II and III. The HQI scores explained 95 percent of the variation in trout biomass for the test streams and the relatively high multiple correlation coefficient (R = 0.98) strongly suggests a close relationship between HQI scores and trout biomass.

Analysis of the residual errors for the model demonstrated that 50 percent of the study sites had a predicted trout biomass within 10 pounds per acre (11.2 kg per ha) of the measured biomass. At 65 percent of the sites, the model predicted the biomass within 25 pounds per acre (28 kg per ha) and at 85 percent of the streams, model accuracy was within 50 pounds per acre (56 kg per ha).

Assuming that trout standing crop is a function of habitat quality, the demonstrated close relationship between HQI scores and trout biomass indicates that the Habitat Quality Index is a realistic measure of habitat quality in Wyoming trout streams.

The next step in this habitat evaluation study was to use the HQI model and evaluation system to develop a standard definition of a trout Habitat Unit. The concept of a unit of habitat measure called a "Habitat Unit" was first noted in Fish and Wildlife Service (1974), but was not defined, standardized, or otherwise explained. For the purpose of the present study, a trout Habitat Unit (HU) is defined as follows: One trout Habitat Unit (HU) is the amount of habitat quality required to produce an increase, in the trout standing group, of 1 pound per acre (1 kg per ha).

The amount of habitat quality needed to produce an increase of 1 pound per acre, or the value of 1 HU, was then determined so that the value of a given habitat could be expressed in terms of standard HU's. This was done using the multiple regression analysis or HQI data and the HQI model.

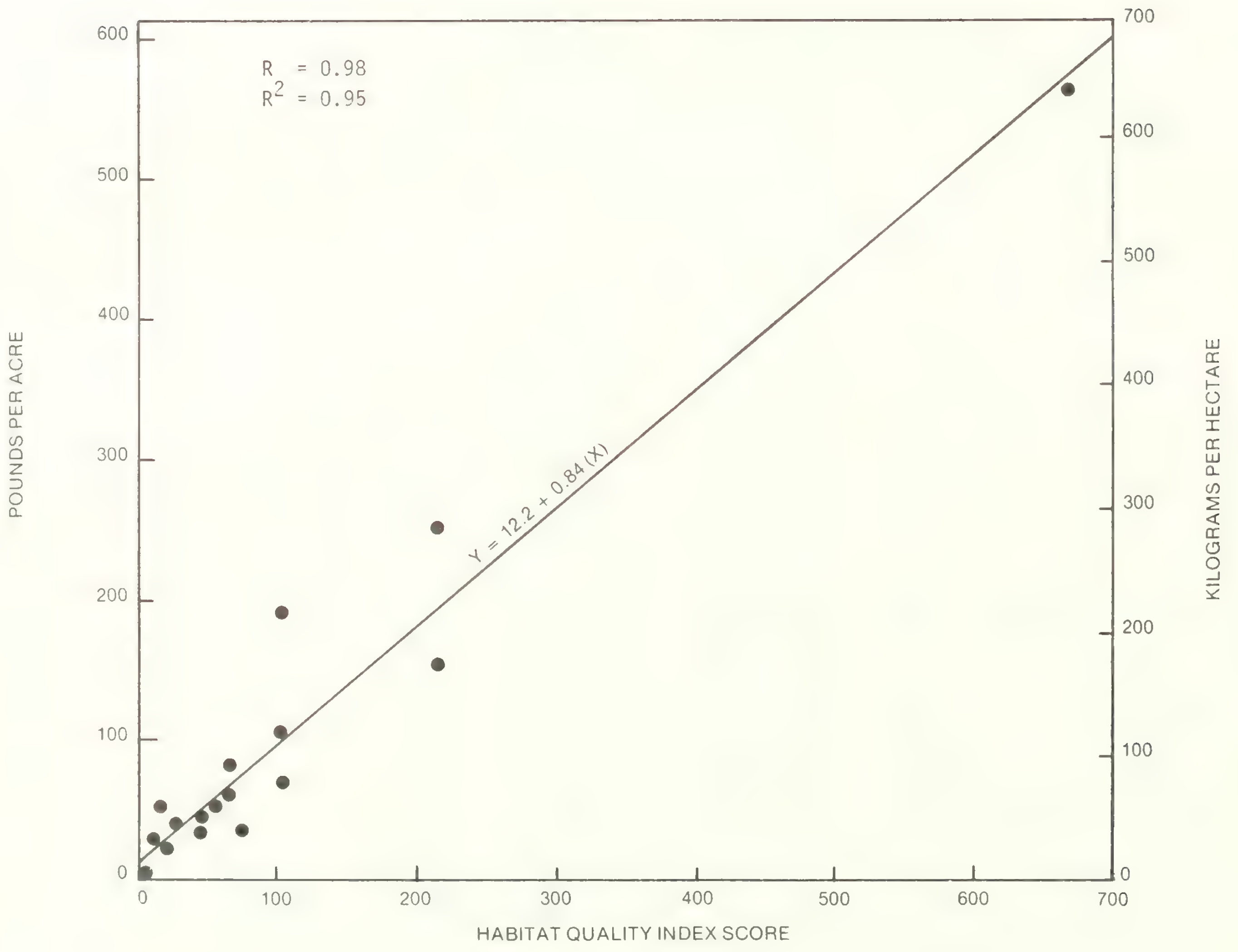


Figure 1. Relationship between HQI score and trout biomass in Wyoming streams.

For convenience, the value of one trout HU, in a stream, is referred to as the Habitat Unit Coefficient (θ_S) (Theta sub-S). Then using the HQI data analysis, as expressed in Figures 1 and 2, the Habitat Unit Coefficient was calculated in the following way:

Using the equation: $Y = 12.2 + 0.84(X)$

Note that:

If $Y = 31$, for example,

$$\text{then } X = \frac{31 - 12.2}{0.84} = 22.38$$

and if, $Y = 30$

$$\text{then, } X = \frac{30 - 12.2}{0.84} = 21.19$$

and since, $22.38 - 21.12 = 1.19$

Then $\theta_S = 1.19$, which is the amount of habitat quality, as measured by the HQI, needed to produce an increase, in the trout standing crop, of 1 pound per acre (1 kg per ha).

To calculate the value of a given trout stream habitat requires only the relationship: H_S = HQI times θ_S

where,

H_S = the Habitat Value of a trout stream

HQI = the Habitat Quality Index score

θ_S = the Habitat Unit Coefficient = 1.19

Thus, if a given trout stream had a HQI score of 50, then the value of that habitat would be 50 x 1.19 = 59.5 trout HU.

An additional objective of this habitat evaluation study was to develop a reasonable method for computing HU loss or gain at proposed reservoir sites. Comparison of HU loss or gain, between a proposed reservoir and the stream it would replace, presents a thorny problem because two entirely different types of trout habitat are represented. The problem is further complicated by the fact that the total area of the stream within the reservoir take-area is only a fraction of the total area represented by the reservoir. Thus, in the calculation procedure outlined in Fish and Wildlife Service (1974), the relatively huge area of a proposed reservoir completely factors out any other consideration, which means that even the very best trout stream could never demonstrate its true value--even if the reservoir which replaced it was the poorest type possible (i.e., high turbidity, temperature extremes, and extreme water level fluctuation) because the reservoir, with its larger area, would always have more total HU than would the stream.

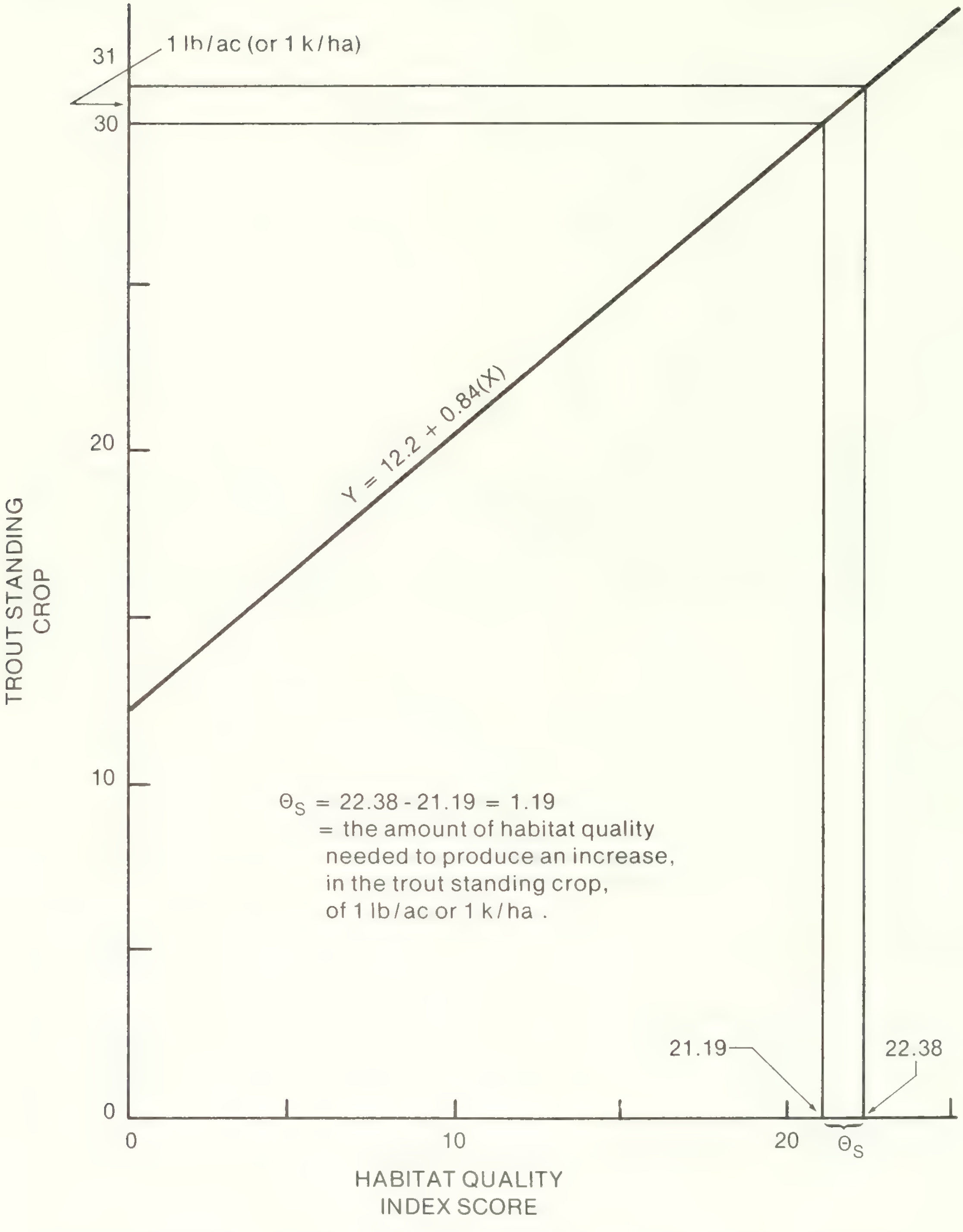


Figure 2. Determination of the habitat unit coefficient (θ_S) for Wyoming streams. Note that (θ_S) is merely the amount of change in the HQI score with a given amount of change in the trout biomass.

To get away from these problems and determine the true relationship between a trout stream and a proposed reservoir requires the introduction of some additional concepts.

First, note that a proposed reservoir on a Wyoming trout stream can be evaluated using Ryder's Morphoedaphic Index (MEI) and the data from an ongoing study of MEI relationship to fish biomass on several Wyoming reservoirs and lakes (Ryder 1965, Ryder et al. 1974, Facciani 1976). The Wyoming MEI work is summarized in Appendix VIII. Both the Ryder and the Facciani work have demonstrated a close relationship between the MEI and fish biomass.

Since new reservoirs on Wyoming trout streams are almost always essentially trout producers for the first few years after impoundment, the assumption is valid that the MEI is a good measure of the potential trout biomass in a proposed reservoir. A Habitat Unit Coefficient (θ_R) for reservoirs can be calculated in the same way as was done for streams. Using the model: log yield = 0.7171 + (1.0251) log MEI, from Facciani's multiple regression analysis, the value of one trout HU for reservoirs (θ_R) was found to be 0.17. The Habitat Value for the proposed reservoir (H_R) is given by the relationship:

$$H_R = \text{MEI times } \theta_R = \text{MEI } (0.17)$$

The second concept that is needed is the concept of an ecological completeness factor (Appendix IV). Ecological completeness is a measure of the ability of a trout to complete its life cycle in a specific aquatic habitat. If a trout cannot complete its life cycle (egg to egg) in a given body of water because of some environmental deficiency, then that body of water is certainly not an ecologically complete habitat. As such, it would be of reduced value to man as a trout producer. In fact, without the hatchery product, such a habitat would be a virtual biological desert for trout. If a trout population can reproduce to some extent, but not enough to maintain the fishery without help from the hatchery product, then the population must be considered to be biologically precarious. At best, such a population would be unstable and, under extreme circumstances, it could be extirpated.

The third concept is that of a Habitat Integrity factor (Appendix V). Habitat integrity is a measure of the geological and biological aging of a reservoir with reference to trout productivity. That is, how long can a reservoir be expected to function as a trout producer before it fills up with silt and organic debris. Although geological and biological life expectancies are not synonymous from the standpoint of trout production, generally the silting in and changing of the water chemistry and physical features of a reservoir will depreciate trout production. Actual habitat is lost by silt deposition, and perhaps more important, by a depreciation of the available nutrients and by an increase in fish species other than trout. An example of this sort of thing is offered by 76-year-old Ennis Reservoir on the Madison River in Montana where not only the reservoir trout fishery is threatened by the silting-in process, but the river fishery below the reservoir is endangered by warm, turbid water from the now shallow reservoir (Fischer 1976).

Note that while most reservoirs have a relatively short life span, a stream, in the same time span, should remain basically the same. Thus, a stream will always have a Habitat Integrity value of unity (1.0).

Using the concepts discussed above, calculation of HU loss or gain has been demonstrated for two proposed reservoirs on Wyoming streams (Appendices VI and VII). The result of these calculations shows that a reservoir on a blue ribbon trout stream would result in a loss of 5,094 trout HU (Table 2). Or stated another way, Kendall Reservoir would offer only 58 percent of the trout HU possible if the Green River were left alone. The blue ribbon stream would offer 173 percent more trout HU than would be possible if the reservoir replaced the stream. On the other hand, a reservoir constructed on a poor trout stream would show a gain of 88 trout HU, with the result that Grayrocks Reservoir would have 276 percent more trout HU than would the Lower Laramie River without the reservoir.

TABLE 2. Comparison of Habitat Unit Loss or Gain for Proposed Reservoirs on Poor and Blue Ribbon Trout Streams

Reservoir	Potential HU		HU loss or gain with the reservoir
	Without reservoir	With reservoir	
Kendall on the Upper Green River, a blue ribbon trout stream	12,046	6,952	-5,094
Grayrocks on the lower Laramie River, a poor trout stream	50	138	+88

This type of comparison demonstrates that a reservoir constructed on the blue ribbon trout stream would result in a considerable loss of the trout resource in that area. However, a reservoir constructed on the poor trout stream would add to the available trout resource in that area, at least during the first years of reservoir life.

The Habitat Evaluation system outlined herein has a number of potential uses, which include:

1) Prediction of trout standing crop, which would be valuable in those situations where trout population estimates are impractical or impossible;

2) Evaluation of trout habitat in terms of standard HU, for example, inventories of trout habitat or evaluation of habitat improvement or habitat degradation; and

3) Comparison of trout habitat loss or gain at proposed water development projects for input to the decisionmaking process.

The habitat evaluation system outlined above is specific for trout waters in Wyoming, but the system would probably be usable in other Rocky Mountain States having similar stream habitat types. Use in other localities, especially for other fish species, would require revision of the HQI rating criteria and a study to validate the relationship between HQI rating criteria and a study to validate the relationship between HQI scores and biomass of the target species. However, the basic approach and principles remain the same and all that would be required is adaptation to the new situation.

The HQI system presumes a high degree of professional and technical competence and expertise for its use, especially in the field evaluation. For example, recognition of what constitutes trout cover in a given stream is best done by someone familiar with the stream and the requirements of the target species, as well as where the fish have been found during past electrofishing and fishing expeditions.

Note that collection of field data for use in the habitat quality index is restricted to the critical period, which is defined as that period from 1 August to 15 September. This restriction was introduced to reduce, as much as possible, the normal variation inherent in natural systems, especially in the fish food organisms.

LITERATURE CITED

Facciani, Steve. 1976. The morphoedaphic index, a fish yield estimator, as demonstrated by purse-seine catches in Wyoming, Appendix VIII. In Binns, N.A. 1976, Evaluation of Habitat Quality in Wyoming Trout Streams. Annu. Meeting Am. Fish. Soc., Dearborn, Michigan, 20 September 1976, Multilithed rep. 33 pp.

Fischer, Hank. 1976. The lower Madison. Montana Outdoors (May/June). pp. 10-14.

Fish and Wildlife Service. 1974. Ecological Planning and Evaluation Procedures--A Report of the Joint Federal-State-Private Conservation Organization Committee. Washington, D.C., multilithed rep. 269 pp.

Ryder, R.A. 1965. A method for estimating the potential fish production of north-temperate lakes. Trans. Am. Fish. Soc. 94(3):214-218.

Ryder, R.A, S.R. Kerr, L.H. Loftus, and H.A. Regier. 1974. The morphoedaphic index, a fish yield estimator--review and evaluation. J. Fish. Res. Board Can. 31:663-688.

Water Resources Council. 1973. Water and related land resources--establishment of principles and standards for planning. Fed. Register 38(174), Part III. 180 pp.

Watt, K.E.F. 1968. Ecology and Resource Management. McGraw Hill Book Co., New York. 357 pp.

APPENDIX I

STREAM ATTRIBUTES AND THEIR RATING CRITERIA FOR USE IN THE HABITAT QUALITY INDEX

CRITICAL PERIOD STREAM FLOWS[1]

Rating	Criteria
0	Critical period water flow, if present at all, is inadequate to support trout and is the critical limiting factor for trout. Trout may be present at other times of the year due to migration or stocking, but flows during the critical period are such as to mandate trout to leave the area or die. Stream flow at this time is less than 10 percent of average daily flow.[2]
1	Critical period water flows appear to be the most important limiting factor for trout, but other limiting factors, such as temperature, may be acting in concert with low flows to limit trout numbers. However, the basic problem is lack of water. Enough stream flow is present though to support a few scattered trout during the critical period. Stream flow at this time is between 10 and 15 percent of average daily flow.[2]
2	Critical period flows are adequate for a small to moderate trout population, but are low enough to seriously limit numbers of trout that can be supported. Stream flows that are low enough to be crucial to trout and that may seriously limit the population may occur every few years or so. Other limiting factors, such as temperature, may be of equal importance with water flow in limiting the trout population. Stream flow at this time is usually between 16 and 25 percent of average daily flow.[2]
3	Critical period water flows are usually not limiting to trout, but crucially low flows may occur every few years or so. Flow levels are adequate for moderate to large numbers of trout, but are still judged to below the level needed for optimal trout production. Stream flow at this time is between 26 and 55 percent of average daily flow.[2]
4	Critical period water flows are very seldom limiting and are usually adequate for optimal trout production, assuming that other important limiting factors are satisfactory. Stream flow at this time is greater than 55 percent of average daily flow.[2]

---

[1] For the purposes of this index, consider the critical period to be August and early September when most streams will be at base or low flow.

[2] Consider average daily flow figures only when U.S. Geological Survey gauging station records are available.

ANNUAL STREAM FLOW VARIATION

Rating	Criteria
0	Extreme fluctuation in stream flow and stream is intermittent.
1	Extreme fluctuation between flood and base flows, but stream is seldom completely dry. Base flow may be variable and is often very limited when compared to size of high water channel.
2	Fluctuation between flood and base flows is pronounced, but moderate in effect. The stream is never dry or nearly so. Base flow is fairly stable and occupies up to two-thirds of the high water channel.
3	Small fluctuation in stream flow. Base flow is quite stable and occupies most of the stream channel.
4	Little or no fluctuation in stream flow. Base flows are very stable and usually bank to bank.

Note that measurements are to be taken only in the time period from 1 August to 15 September.

TEMPERATURE[1]

Rating	Criteria	
	Low range	High range
0	<43° (<6.1°)	>80° (>26.7°)
1	43 - 46° (6.1 - 7.8°)	76 - 79° (24.5 - 26.1°)
2	47 - 50° (8.4 - 10°)	71 - 75° (21.6 - 23.9°)
3	51 - 54° (10.5 - 12.2°)	66 - 70° (18.9 - 21.1°)
4	55 - 65° (12.8 - 18.3°)	

---

[1] Maximum summer temperature in degrees F. (degrees C. in parenthesis).

MEAN VELOCITY[1]

Rating	Criteria	
	Low range	High range
0	<0.25	>4.0
1	0.25 - 0.49	3.50 - 3.99
2	0.50 - 0.99	3.0 - 3.49
3	1.0 - 1.49	2.50 - 2.99
4	1.50 - 2.49	

Note that measurements are to be taken only in the time periods from 1 August to 15 September.

INSTREAM HIDING AND RESTING FACILITIES (COVER)

Rating	Criteria
0	Very poor, total cover area occupies less than 10 percent of the total area.
1	Poor, total cover area occupies from 10 to 25 percent of the total area.
2	Fair, total cover area occupies from 26 to 40 percent of the total area.
3	Good, total cover area occupies from 41 to 55 percent of the total area.
4	Excellent, total cover area occupies more than 55 percent of the total area.

Note that measurements are to be taken in the time period from 1 August to 15 September.

---

[1] Time-of-travel velocity in feet per second.

Rating	Diversity Score (D_s)[1]	Remarks
0	<0.80	The aquatic bottom fauna has poor diversity and balance. There may be many organisms present, but usually relatively few "species"[2] are present. One or two groups, such as annelid worms, snails, or midges, may compromise the bulk of the fauna.
1	0.80 to 1.19	The aquatic bottom fauna has fair diversity and balance. Organisms may be numerous, but the number of "species"[2]

---

[1] For the purposes of this index, Diversity Score (D_s) is defined as follows: D_s = anti-log D.^{D} is calculated for each "species" group from the formula:

$D = \sum_{I=1}^{n} P_I \log P_I$, when P_1 is defined as I/n and n is the number of organisms, then the formula reduced to D = log n, as discussed in Watt (1968), D is the mean of all the D values.

[2] For the purpose of this index, the word "species," as thus marked, is defined as meaning the following taxonomical level for the respective major aquatic faunal groups:

Group	Level	Example
Diptera (Flies)	Family	Tendipedidae
Ephemeroptera (Mayflies)	Genus	Baetis
Plecoptera (Stoneflies)	Genus	Acroneuria
Trichoptera (Caddisflies)	Genus, except Limnephidilidae and Philopatomidae	Hydropsyche
Coleoptera (Beetles)	Family	Elimidae
Odonata (Dragon and damsel flies)	Family	Gomphidae
Lepidoptera (Aquatic caterpillars)	Family	Pyralididae
Gastropoda (Snails)	Family	Lymnaeidae
Nemotoda (Roundworms)	Phylum	Nematoda
Annelida (Worms)	Class	Oligochaeta
Hydracarina (Aquatic mites)	Order	Hydracarina
Amphipoda	Order	Amphipoda

Rating	Diversity Score (D_s)[1]	Remarks
		present is limited. One or two groups may numerically dominate the fauna.
2	1.20 to 1.89	The aquatic bottom fauna has mediocre diversity and balance. A moderate number of "species"[2] may be present, but the overall faunal picture is often numerically off balance since only a few groups may comprise the bulk of the fauna.
3	1.90 to 3.99	The aquatic bottom fauna has good diversity and balance. Overall, the fauna has a large number of "species" present from a wide variety of groups. However, the diversity score is not the best, which indicates some type of habitat weakness and resultant community instability.
4	4.0 or greater	The aquatic bottom fauna has excellent diversity and balance. Many groups are well represented, which indicates quality habitat with many niches and optimal conditions, as well as a high degree of community stability.

TROUT FOOD - ABUNDANCE[1]

Rating	Criteria
0	Rare, with less than 25 organisms per square foot.
1	26 to 99 organisms per square foot.

---

[1] Surber square foot samples from riffles only. Use average number or organisms per square foot as determined from several samples taken on representative riffles. Exclude aquatic Annelida from totals used for abundance, but note they should be included for diversity and type calculations.

TROUT FOOD - ABUNDANCE (Concluded)

Rating	Criteria
2	Common, with 100 to 249 organisms per square foot.
3	250 to 499 organisms per square foot.
4	Numerous, with 500 or more organisms per square foot.

Bottom fauna samples are to be taken in the time period from 1 August to 15 September.

NITRATES (ppm)

Rating	Criteria		
	Low range		High range
0	0.001 - 0.009	or	>2.0
1	0.01 - 0.04	or	0.91 - 2.0
2	0.05 - 0.09	or	0.51 - 0.90
3	0.10 - 0.14	or	0.26 - 0.50
4	0.15 - 0.25		

Note that measurements are to be taken only in the time period from 1 August to 15 September.

Nitrate Analysis is to be done by the Pheuoldisulfonic Acid Method, as outlined by "Standard Methods for the Examination of Water," American Public Health Association, 1971.

MEAN WIDTH[1]

Rating	Criteria
0	<2 or >100
1	2 - 6 or 75 - 99
2	7 - 11 or 50 - 74
3	12 - 17 or 23 - 49
4	18 - 22

Note that measurements are to be taken only in the time period from 1 August to 15 September.

BANK STABILITY[2]

Rating	Criteria
0	75 - 100 (very poor)
1	50 - 74 (poor)
2	25 - 49 (fair)
3	10 - 24 (good)
4	0 - 9 (excellent)

Note that measurements are to be taken only in the time period from 1 August to 15 September.

---

[1] Mean top width, in feet, of wetted area determined from a series of representative cross section transects in the study area.

[2] Footage of eroding banks in study section, expressed as percent of total footage of both banks.

APPENDIX II

EXAMPLE OF STREAM ATTRIBUTE RATING SHEET USED IN THE HABITAT QUALITY INDEX

HABITAT QUALITY INDEX ATTRIBUTE RATING SHEET
STREAM Green River at Blackmon Easement
TROUT STANDING CROP 42.5 LBS/AC

ATTRIBUTE		DATA	RATING
Primary factors			
(X_1)	Critical Period Stream Flow	5 year mean critical Period Flow = 85% ADF	4
(X_2)	Annual Stream Flow Variation		2
(X_3)	Maximum Summer Stream Temperature	70°F	3
Secondary Factors			
(S_1)	Water Velocity	Time of travel velocity = 2.67 fps	3
(S_2)	Cover	About 30%	2
(S_3)	Fish Food Diversity	D_s = 0.907	1
(S_4)	Fish Food Abundance	206.9 organisms/sq. ft.	2
(S_5)	Nitrates	0.02 ppm	1
(S_6)	Stream Width	94 feet	1
(S_7)	Stream Bank Stability	Good	3

APPENDIX III

EXAMPLE OF HABITAT QUALITY INDEX CALCULATIONS FROM ATTRIBUTE RATINGS THROUGH HABITAT VALUE

Habitat Quality Index Calculations sheet

Green River at Blackmon Easement

$X_1 = 4$ $P = (3)\ (2)\ (1)\ (2)\ (1)\ (1)\ (3)$

$X_2 = 2$

$X_3 = 3$ $P = 36$

$\log (1 + X_1) = \log (5) = 0.69897$

$\log (1 + X_2) = \log (3) = 0.47712$

$\log (1 + X_3) = \log (4) = 0.60206$

$\log (1 + P) = \log (37) = 1.56820$

$$\log (HQI + 1) = (-1.18257) + (0.97329) \log (1 + X_1) + (1.65824) \log (1 + X_2) + (1.44821) \log(1 + X_3) + (0.30762) \log(1 + P)$$

$$\log (HQI + 1) = (-1.18257) + (0.97329)(0.69897) + (1.65324)(0.47712) + (1.44821)(0.60206) + (0.30762)(1.56820)$$

$$= (-1.18257) + (0.68030) + (0.79118) + (0.87191) + (0.48241)$$

$$= 1.64323$$

Antilog $= 43.89$

$HQI = 43.9 - 1.0 = 42.9 = 43$

Habitat Value $= H_s = HQI\ x$

$= 43\ (1.19)$

$= 51.17 = 52$ HU

Where HU = Habitat Unit(s)

θ_s = Habitat Unit coefficient for trout streams

= 1.19 = the value of one Habitat Unit

H_s = Habitat Value for a trout stream

HQI = Habitat Quality Index Score (and predicted trout standing crop).

APPENDIX IV

RATING CRITERIA FOR THE ECOLOGICAL COMPLETENESS FACTOR

Factor	Criteria
0.1	Trout are unable to complete their life cycle.
0.5	Trout are able to complete their life cycle, but the trout population may be biologically precarious.
1.0	Trout are able to complete their life cycle and the trout population is never biologically precarious.

APPENDIX V

RATING CRITERIA FOR THE HABITAT INTEGRITY FACTOR

Factor	Criteria
0.1	The reservoir will be over 75% filled in 100 years.
0.5	The reservoir will be 25 to 75% filled in 100 years.
1.0	The reservoir will be less than 25% filled in 100 years.

APPENDIX VI

CALCULATION OF HABITAT UNIT (HU) LOSS OR GAIN FOR THE PROPOSED KENDALL RESERVOIR ON THE UPPER GREEN RIVER, A BLUE RIBBON TROUT STREAM

Green River without Kendall Reservoir				Green River with Kendall Reservoir
26.64	HQI	Index value (MEI) (times)		5.17
1.19	θ_s	HU coef. (gives)	θ_r	0.17
31.70 HU	H_s	Habitat value (times)	H_r	0.88 HU
1.0		Ecological Completeness (times)		0.5
1.0		Habitat integrity (times)		1.0
380 acres		Area (Equals)		15,800 acres
12,046 HU		Total HU Present		6,952 HU

APPENDIX VII

CALCULATION OF HABITAT UNIT (HU) LOSS OR GAIN FOR THE PROPOSED GRAYROCKS RESERVOIR ON THE LOWER LARAMIE RIVER

Laramie River without Grayrocks Reservoir				Laramie River with Grayrocks Reservoir
4.65	(HQI)	Index value (times)	(MEI)	20.35
1.19	θ_S	HU coef. (gives)	θ_R	0.17
5.43 HU	H_S	Habitat value (times)	H_R	3.46 HU
0.1		Ecological completeness (times)		0.1
0.1		Habitat integrity (times)		0.1
92 acres		Area		3,450 acres
50 HU		Total HU present		138 HU

APPENDIX VIII

ABSTRACT

THE MORPHOEDAPHIC INDEX, A FISH YIELD ESTIMATOR AS DEMONSTRATED BY PURSE SEINE CATCHES IN WYOMING

By

Steve Facciani

During the course of Wyoming's Commercial Fisheries Investigations (fish population estimates) using a purse seine, it was discovered that catches (one haul sampled approximately 1 surface acre) in various lakes and reservoirs reflected Ryder's Morphoedaphic Index. Table 1 presents the findings of these evaluations for trout reservoirs only. Although other reservoirs and lakes were samples and compared with the MEI, in order to correlate this index with trout stream productivities (expressed as trout habitat units) only those waters which met the following criteria were incorporated into this regression:

1. Relatively homogeneous climatic conditions within the set;

2. Stoichiometry within the ionic spectrums resulting in fairly constant ionic ratios;

3. Approximately proportional flushing rates per unit of lake volume; and

4. Inorganic turbidity on the same order of magnitude for all lakes in the set.

TABLE 1[1]

	MEI	LBS. PER SEINE HAUL (Acre)
Buffalo Bill	2.8	12.41
Alcova	4.43	36.75
Flaming Gorge	4.8	24.07
Pathfinder	7.32	34.19
DeSmet	9.7	53.58

$$\text{Log Yield} = (.7171) + (1.0251)\ \text{Log MEI}$$

$$R_2 = .8914$$

$$R = .79$$

$$Y = (5.2141) \times 1.0252$$

Significant difference from 0 at the 95% level

---

[1] A sixth lake was also sampled with an MEI of 0.06 and with an actual catch rate of 0 trout per purse haul. Consequently this lake was not entered into this regression, however findings are consistent with this model.

NATURAL AREA CLASSIFICATION SYSTEM: A STANDARDIZATION SCHEME FOR BASIC INVENTORY OF SPECIES, COMMUNITY, AND HABITAT DIVERSITY

Albert E. Radford
Botany Department
University of North Carolina
Chapel Hill, North Carolina 27514

Abstract: Any natural area classification system should include biotic assemblages (vegetation with accompanying fauna), climatic regime(s), soil system(s), geologic formation(s), hydrology, and land form(s) by physiographic province hierarchically arranged with each entry at each level circumscribed and encoded. The System proposed represents an effort to produce a basic standardization scheme for more efficient and effective inventory and storage and retrieval of information on natural areas, vegetation, floras, and rare, endangered and threatened species.

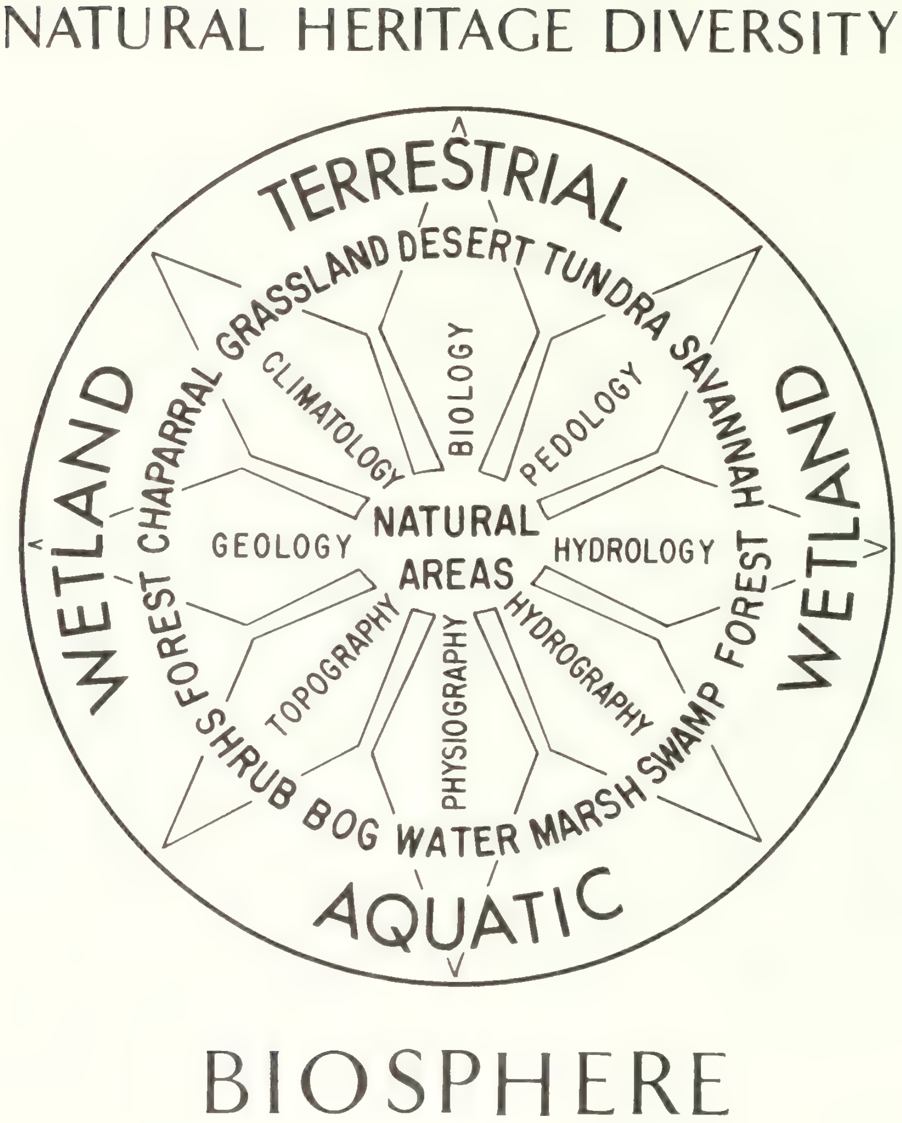
INTRODUCTION

Our Natural Heritage requires a holistic, comprehensive classification of the natural features and processes in our biotic and abiotic environment for the inventory and conservation of species, communities, and habitats.

The Natural Heritage for any province includes: (a) Vegetation (with animal dependents or communities), (b) climate, (c) soils, (d) geology, (e) hydrology, (f) topography, and (g) hydrography. All of these themes are interacting but independent systems that compose the ecosystems, biomes and natural areas (Figure 1). The basic energy driving the system is sunlight; the basic raw materials are from the intrusive and extrusive magmas, oceans, and atmosphere. Vegetational composition (with animal dependents) distribution, and development are dependent upon climate, soils, geology, and topography acting through time. Microclimates are dependent upon vegetation, soils, geology, and topography. Soil composition, distribution, and development are dependent upon vegetation, climate, geology, and topography acting through time. Geological structures, formations, and sedimentary rocks are dependent upon vegetation, climate, soils, topography, and time. Topographic land forms and features, structures, and development are dependent upon vegetation, climate, soils, geology, and time.

Who knows which component of our habitat is more significant than another in the maintenance of species diversity, in the origin, migration, and evolution of species, faunas, floras, and communities? Who realizes the significance and the role of species diversity in maintaining habitat diversity? A comprehensive approach is the way to insure total species/habitat diversity in our conservation efforts. All of these interacting and interdependent themes and systems form the bases for the natural area classification scheme used in this report.

The ecological natural history themes for any conservation effort should provide the framework for a comprehensive survey of biotic and abiotic features. All types of communities, from the pioneer to the climax, developed



NATURAL HERITAGE DIVERSITY

BIOSPHERE

Figure 1. The biosphere showing ecosystems, biomes, and natural areas on the outer circles and habitat components on the radic.

during time over the different rock and water types, under each significant climatic regime on the major topographic-hydrographic features, should be included in the representative site samples of a complete survey of the area. The successional communities, the topographic-edaphic climaxes, and the continua should be part of the master theme study or conservation effort. Biogenesis has to be integrated with pedogenesis in explaining the present and past development of species and communities; climatogenesis and phylogenesis have to be coupled with succession and soil formation to explain the present composition and distribution of biotic assemblages. Man will have to try to conserve the total diversity of species in as broad a range of habitats as possible within the different climates in each province, in order to understand the origin, migration, and evolution of species, the floras and the faunas, as well as the productivity and composition of present communities.

Classification is a hierarchical arranging of objects or taxa into ranks and a horizontal ordering of objects or taxa into compartments. The purpose of classification is to arrange objects or taxa in a way that gives us the greatest possible command of our knowledge, makes the most efficient and effective use of our information and leads us most directly to the acquisition of more data, information, and knowledge. Classification is not static; it should be dynamic. Our expanding knowledge of natural areas will be reflected in open, changing systems.

This Natural Area Classification System is an effort to make more efficient and effective (a) the study of floristic and vegetational systematics and (b) the classification of elements of the ecosystem for ecological characterization, classification, nomenclature, and identification of plant (and animal) species and communities (Radford et al. 1976).

The System is based upon the following assumptions:

1. Each species is selectively and uniquely adapted to a habitat.

2. Species diversity is related to habitat diversity within an area.

3. Habitat diversity is related to the diversity of climate, geology, soils, hydrology, and topography within an area.

4. Species assemblages are recurring combinations under similar habitat conditions within an area at a given time.

5. Species assemblages are the result of the interaction of species and habitat diversity in an area through time.

SYSTEM

The Natural Area Classification System herein, based primarily on vascular plants, has been designed for inventory and analysis of natural areas, vegetation, floras, and rare and endangered species in the United States. This system has been devised to cover: (1) All types of successional communities; (2) all types of topographic-edaphic climaxes; (3) all vanishing, rare, endangered, or relict species, communities and ecosystems; and (4) all disjunct species and communities. The application of a broad natural area classification for any province is necessary for perspective in theme analysis and categorization, and for a complete conservation of our Natural Heritage.

Hierarchically the classification system (Table 1) has three orders or levels: the first, System (A), with a suborder (AA) e.g., "subsystem" for vegetation and "suborder" for soils; the second, Class (B), with a suborder (BB) e.g., "community class" for vegetation and "suborder" for soils; and the third, Type (C), with a suborder (CC) e.g., "community type" for vegetation and "series" for soils. The themes or vertical files are vegetation (biotic communities), climate, soils, geology, hydrology, topography, hydrography and physiography. In the geology/hydrology and topography/hydrography themes the geologic and topographic characters are usually used for upland and flatland systems. Hydrologic and hydrographic characters are normally used for the wetland and aquatic systems.

VEGETATION (BIOTIC COMMUNITIES)

The vegetation community system, first order, is based primarily on plant habit arranged in a time or successional theme from pioneer annuals to climax angiosperm forests (I-XV; algal, bryological, and animal systems will be added to the classification scheme) with upland or flatland (I-VII) and lowland (VIII-XV) toposequences related to moisture (Table 2). The first suborder is a combination of community subsystem and rock/water class (eg. basic pioneers, calcareous perennials, and wet calcareous shrub). The second order is composed of community cover classes (Table 2) which are combinations of distinctive physiognomic assemblages with habitat-habit characters (eg. spring succulents, grass balds, and pine barrens). The Community Cover Classes are broad groups or assemblages of plants that have been described in the literature over a long period of time. As more inventory experience is gained the list of Cover Classes will be extended. The second suborder consists of Community Classes which are characterized by dominants in a broad or generic sense in each layer of the community (eg. Fagalean-Ericalean Community Class might be a combination of oaks (or a single one) in the canopy with a shrub layer below dominated by one or more heaths). The third order of vegetation is the Community Cover Type which would have only the stand dominant indicated, e.g. eastern hemlock, sea oats, or purple laurel (Table 3).

The basic Community Type, third suborder, should be based on quantitative data for a biotic assemblage with a uniform microclimate and edaphic situation (pH, moisture, and texture classes should be relatively uniform throughout the area). A one-layered community type would be denoted by a monomial (eg. Reed grass Phragmites communis). Stratified (two-layered) communities are indicated by a binomial with the first name based on dominant "subcanopy" species (eg. community type).

Community type Chestnut oak--Low blueberry

Canopy dominant--Subcanopy dominant

(Shrub layer with more cover than herb layer, herbs scattered or essentially absent)

Community class Oak-hickory forest--Heath

Community type Buckeye-basswood--Glade fern

Canopy codominants--"Subcanopy" dominant

Table 1. Summary of Natural Area Classification System

	General Organization							
Order and Suborder	I Vegetation	II Climate	III Soil	IV Geology	V Hydrology	VI Topography	VII Hydrography	VIII Physiography
A	Community System	Climatic Regime	Soil Order	Formation Age-System	Water System	Landform	Water Body	Physiographic Region
AA	Community Subsystem	Climatic Subregime	Soil Suborder	Geological Formation	Water Subsystem	N. A.[a/] Landform	N. A. Water Body	Physiographic Province
B	Community Cover Class	Temperature Zone	Soil Great Group	Rock Class	Water Class	Topographic[b/] Feat.	Hydrologic Feat.	Physiographic Subprovinces
BB	Community Class	Moisture Zone	Soil Subgroup	Rock Subclass	Water Subclass	Relief Feat.	Relief Feat.	County-State
C	Community Cover Type	Temperature Type	Soil Family	Rock Type	Water Type	Slope Exposure	Current Type	Latitude-Longitude
CC	Community Type	Moisture Type	Soil Series	Mineral Composition	Water Turbidity	Slope Degree	Bottom Composition	Locality

[a/] N. A. = Natural Area

[b/] Feat. = Feature

Table 2. Natural Area Classification System - Vegetative Systems

IA VEGETATIVE SYSTEMS	IAA VEGETATIVE SUBSYSTEMS (SS)
1. PIONEER HERB	1. Basic, 2. Calcareous, 3. Carbonaceous, 4. Ferruginous, 5. Saline, 6. Siliceous Pioneers
2. PERENNIAL FORB	1. Basic, 2. Calcareous, 3. Carbonaceous, 4. Ferruginous, 5. Saline, 6. Siliceous Forbs
3. GRASS	1. Basic, 2. Calcareous, 3. Carbonaceous, 4. Ferruginous, 5. Saline, 6. Siliceous Grasses
4. SCRUB-SHRUB	1. Basic, 2. Calcareous, 3. Carbonaceous, 4. Ferruginous, 5. Saline, 6. Siliceous Shrubs
5. WOODLAND	1. Basic, 2. Calcareous, 3. Carbonaceous, 4. Ferruginous, 5. Saline, 6. Siliceous Woodland
6. GYMNOSPERM FOREST	1. Basic, 2. Calcareous, 3. Carbonaceous, 4. Ferruginous, 5. Saline, 6. Siliceous Gymnosperms
7. ANGIOSPERM FOREST	1. Basic, 2. Calcareous, 3. Carbonaceous, 4. Ferruginous, 5. Saline, 6. Siliceous Angiosperms
8. VASCULAR AQUATIC PLANT	1. Fresh, 2. Brackish, 3. Saline, 4. Haline, 5. Bog (Acid) Aquatic Herbs
9. WETLAND PIONEERS	1. Fresh, 2. Brackish, 3. Saline, 4. Haline, 5. Bog (Acid) Wetland Pioneers
10. MARSH HERBS	1. Fresh, 2. Brackish, 3. Saline, 4. Haline, 5. Bog (Acid) Marsh Perennials
11. MARSH GRASS	1. Fresh, 2. Brackish, 3. Saline, 4. Haline, 5. Bog (Acid) Marsh Grasses
12. WET SCRUB-SHRUB	1. Fresh, 2. Wet Brackish, 3. Saline, 4. Haline, 5. Bog (Acid) Shrubs
13. LOW WOODLAND	1. Fresh, 2. Wet Brackish, 3. Saline, 4. Haline, 5. Bog (Acid) Woodland
14. LOWLAND GYMNOSPERM FOREST	1. Fresh, 2. Wet Brackish, 3. Saline, 4. Haline, 5. Bog (Acid) Gymnosperms
15. LOWLAND ANGIOSPERM FOREST	1. Fresh, 2. Wet Brackish, 3. Saline, 4. Haline, 5. Bog (Acid) Angiosperms

Table 3. Natural Area Classification System - Biotic Communities, Climate, Soil and Other Divisions of Sample Communities[a]

Hierarchies	Bushy Lake - Coastal Plain Wetland	Occoneechee Mountain - Piedmont Disjunct Community	Craggy Wilderness - Mountain Community
VEGETATIVE (I) (Biotic Communities)			
A. COMMUNITY SYSTEM	Vascular Aquatic	Angiosperm Forest	Gymnosperm Forest
AA. SUBSYSTEM	Bog Aquatic Herbs	Siliceous Angiosperm	Siliceous Gymnosperm
B. COMMUNITY COVER CLASS	Waterlily Bed	Oak Slope	Hemlock Slope
BB. CLASS	Nymphaeales	*Fagales-Ericales*	Coniferales
C. COMMUNITY COVER TYPE	*Nymphaea odorata*	*Quercus prinus*	Eastern Hemlock
CC. TYPE	*Nymphaea odorata-Orontium aquaticum-Utricularia* spp.	*Chestnut oak-Low heath*	*Eastern Hemlock-Heath*
CLIMATE (II)[b]			
A. CLIMATIC REGIME	Mesothermal	Mesothermal	Mesothermal
AA. SUBREGIME	Continental Humid	Continental Humid	Continental Humid
B. TEMPERATURE ZONE	Lower Austral	Lower Austral	Transition
BB. MOISTURE ZONE	Average Rainfall	Average Rainfall	Average Rainfall
C. TEMPERATURE TYPE	Medium Frostfree	Average Frostfree	Medium Frostbound
CC. MOISTURE TYPE	Hydric	Dry Mesic	Dry Mesic
SOILS (III)			
A. ORDER	Histosol	Inceptisol	Inceptisol
AA. SUBORDER	Fibrist	Ochrept	Ochrept
B. GREAT GROUP	Medifibrist	Dystrochrept	Dystrochrept
BB. SUBGROUP	Sapric Medifibrist	Typic Dystrochrept	Typic Dystrochrept
C. FAMILY	N.D.[c]	Clayey, kaolinitic, thermal typic dystrochrept	Coarse-loamy, mixed, mesic, typic dystrochrept
CC. SERIES	N.D.	Georgeville	Ashe

Table 3. Continued

Hierarchies	Bushy Lake - Coastal Plain Wetland	Occoneechee Mountain - Piedmont Disjunct Community	Craggy Wilderness - Mountain Community
GEOLOGY (IV)			
A. FORMATION AGE	Pleistocene Sediments	Cambrian Volcanics	Paleozoic Igneous
AA. GEOLOGICAL FORMATION	N.D.	Carolina Slate Belt	Henderson Granite gneiss
B. ROCK CLASS	Carbonaceous	Siliceous	Siliceous
BB. SUBCLASS	N.A.[d]	N.A.	N.A.
C. ROCK TYPE	Muck	Felsite	Granite gneiss
CC. MINERAL COMPOSITION	N.A.	Quartz	Quartz, Mica, Hornblende
HYDROLOGY (V)			
A. WATER SYSTEM	Lacustrine	N.A.	N.A.
AA. SUBSYSTEM	Littoral	N.A.	N.A.
B. WATER CLASS	Bog	N.A.	N.A.
BB. SUBCLASS	Highly Acid	N.A.	N.A.
C. WATER TYPE	Semipermanently Flooded	N.A.	N.A.
CC. TURBIDITY	Blackish	N.A.	N.A.
TOPOGRAPHY (VI)			
A. GENERAL LANDFORM	N.A.	Ridge	Locust Ridge
AA. NATURAL AREA LANDFORM	N.A.	Sheltered Slope	Sheltered Slope
B. TOPOGRAPHIC FEATURE	N.A.	Erosional Ridge	Erosional Ridge
BB. RELIEF FEATURE	N.A.	Moderate Slope	Moderate Slope
C. SLOPE EXPOSURE	N.A.	North Slope	South Slope
CC. SLOPE DEGREE	N.A.	Moderate	Moderate

Table 3. Concluded

Hierarchies	Bushy Lake - Coastal Plain Wetland	Occoneechee Mountain - Piedmont Disjunct Community	Craggy Wilderness - Mountain Community
HYDROGRAPHY (VII)			
A. WATER BODY/LANDFOEM	Terrace	N.A.	N.A.
AA. NATURAL WATER BODY	Bushy Lake	N.A.	N.A.
B. HYDROGRAPHIC FEATURE	Peat-burn	N.A.	N.A.
BB. RELIEF FEATURE	Bottom, Hummock	N.A.	N.A.
C. CURRENT TYPE	None	N.A.	N.A.
CC. BOTTOM COMPOSITION	Peat	N.A.	N.A.
PHYSIOGRAPHY (VIII)			
A. REGION	Coastal Plain	Appalachian Highlands	Appalachian Highlands
AA. PROVINCE	Atlantic CP	Piedmont	Blue Ridge Mts.
B. SUBPROVINCE	Sunderland Terrace	Occoneechee Mt.	Great Craggy Mts.
BB. COUNTY-STATE	Bladen Co., N.C.	Orange Co., N.C.	Buncombe Co., N.C.
C. LATITUDE-LONGITUDE	35°53' N, 78°42' W	36°3'35" N, 79°7'24" W	35°43'45" N, 82°22'0" W
CC. LOCALITY	16 mi. (25.7 Km) s. of Fayetteville	1.5 mi. (2.4 Km) sw. of Hillsborough	1.75 mi. (2.8 Km) sw. of Walker Knob

[a] Natural Areas from North Carolina with one Community System, Temperature Zone, etc. indicated as an illustration.

[b] Climate classification very tentative.

[c] N.D. - not determined.

[d] N.A. - not applicable.

(Herb layer with more cover than shrub, shrub layer essentially absent)

Community class Southern Appalachian Hardwoods--Filicalean perennials

Community type Scirpus americanus--Sagittaria subulata

Emergent dominant--Submerged dominant

Community class Cyperaceous perennials--Alismatalean perennials

Those communities with three distinctive strata would have a trinomial as the community type name:

Community type Chestnut oak--Mountain laurel--Galax

Canopy dominant--Shrub dominant--Herb dominant

(Cover value (5) for each)

Community class Oak-hickory forest--Heath--Diapensialean perennials

Community type Water Tupelo--Duckweed--Coontail

Canopy dominant--Floating dominant--Submerged dominant

Community class Cornalean forest--Lemnaceous herb--Nymphaealean herb

If the community has four distinctive strata then the community type name would be indicated by the dominant from each of the four layers. If vines occur in two or more layers and have a total cover value of (5), then vine dominant(s) should be part of the community type name following (/) at the end of the binomial (eg. Chestnut oak--Low blueberry/Catbrier). Epiphytes with a large cover value should be indicated by (//), then dominant epiphyte name (eg. Water tupelo-Duckweed--Coontail//Spanish moss).

Within a "uniform" topographic-edaphic and microclimatic situation the habitat is not uniform. The Buckeye-basswood--Glade fern community used as an example above has a few stumps and fallen logs with a distinctive flora (hummophytes), a few seepages with some species restricted to them (crenophytes) and walking fern-covered boulders (petrodophytes). In an inventory of this (or any) community the species should be listed by sub-habitat (eg. hummophyte, crenophyte, petrodophyte, epiphyte, or calciphytes on a calcareous lens or shell sand in a siliceous-based community, dry mesophytes over shallow soil in an otherwise mesic habitat, pyrophytes around an old campsite fireplace, aletophytes on trails through the community, etc.) within the general community or habitat summary for that particular area or site.

CLIMATE

The first order of the climatic file should include the climatic regimes according to Koppen (Goode and Espenshade 1950) or some other climatologist (eg. I. Tropical Climate [A], II. Arid Climate [B], III. Mesothermal Climate [C], IV. Microthermal Climate [D], and V. Cryothermic [polar] Climate [E] Table 3). The first suborder might pertain to temperature, such as the classification of C. Hart Merriam (eg. I. Arctic Zone, II. Hudsonian Zone, III. Canadian Zone, IV. Transition Zone, V. Upper Austral Zone, VI. Lower Austral Zone, and VII. Tropical Zone). The second order should include annual average, maximum, and minimum temperatures with the suborder covering annual average, maximum, and minimum rainfall. The third order should include the frostfree days and the suborder, the edaphic moisture classes like those of the U. S. Department of Agriculture (eg. 1. Very Dry-Xeric, 2. Dry-Xeric, 3. Dry-Mesic, 4. Mesic, 5. Wet-Mesic, 6. Wet-Hydric, and 7. Hydric). This is a very tentative classification of climate.

SOILS

The soil file should be based on the soil taxonomy (Soil Survey Staff 1975) of the U. S. Department of Agriculture with soil order (eg. Alfisols, Aridisols, Entisols, Histosols, etc.) and soil suborder as first subrank (eg. Udalfs, Argids, Psamments, Saprists, etc.) (Table 3). The second order would be the Great Group Level--second suborder, the Suborder Level--and the third order, the Family Level--the third suborder, the Series Level.

GEOLOGY

The first order of the geologic file is composed of the broad groups of rocks with age (eg. Devonian sediments, Table 3). Geologic formations compose the first suborder (eg. Dakota Sandstone, Morrison Formation, Great Smoky Conglomerate). The second order classification is based on rock chemistry. The basic rocks (I) are igneous or metamorphosed igneous; the calcareous (II) are essentially sedimentary carbonate rocks; the carbonaceous (III) are those parent materials high in organic content; the ferruginous (IV) are precipitates, sediments, or mestasediments unusually red and high in iron; the saline rocks (V) are salt or salty; and the siliceous (VI) are igneous, sedimentary, or metamorphic rocks high in quartz or silicic acid. The second suborder includes subclasses of each class (eg. ultrabasic, intermediate, etc.). The third order, rock types, are the traditional rocks (eg. granite, marble, shale, diabase, etc.). The third suborder has the primary minerals of rock type indicated (eg. quartz and orthoclase for a granite).

HYDROLOGY

The first order and suborder respectively of hydrology (Table 3) are the ecological system and the subsystem, prepared for the U. S. Fish and Wildlife Service (Cowardin et al. 1976), which includes the marine, estuarine, riverine, lacustrine, and palustrine systems. For example, the first suborder (subsystem) for the marine and estuarine systems is tidal and subtidal; the first suborder for the lacustrine is littoral and profundal.

The water classes, second order hydrology, are based on water chemistry (eg. fresh water, brackish, haline, and saline). The second suborder recognizes classes of salinity, halinity, etc.

The water types, third order hydrology, are based on nontidal and tidal flooding or hydroperiod (eg. nontidal-intermittently flooded, permanently flooded, temporarily flooded, etc.); tidal-irregularly flooded, regularly flooded, and subtidal. The third suborder includes water color or turbidity.

TOPOGRAPHY

Under the topographic land forms the first order includes named broad features such as basin, beach, bluff, hill, plain, ridge (eg. Okeechobee

Plain, Trail Ridge, French Broad Valley, Table 3). The actual natural area feature is the first suborder. The specific types of each topographic feature (usually based on origin) are treated as second order (eg. old deltaic plain, old lacustrine basin, fault ridge). The second suborder, relief, includes the features that are critical as the topographic habitat of the organisms (eg. crevice, flat, pit, scarp, swale, cleavage). The third order includes slope exposure (eg. sw, n, s, e, ne, etc.). The third suborder is slope degree (eg. gentle, moderate, or steep).

HYDROGRAPHY

The hydrographic file (Table 3) includes the named water body or drainage as first order (eg. Chesapeake Bay, Pamlico Sound, Lake Michigan, or Catawba River Drainage). The specific types of each water body or wetland (usually based on origin) are treated as second order (eg. bar estuary, cirque lake, kettle pond, brown-water stream, lacustrine basin, estuarine plain, etc.). The second suborder includes the wetland and aquatic relief features (eg. bar, bench, fan, flat, reef, riffle, shelf, shoal, etc.). The third order includes current type (eg. wind, tidal, marine, etc.). The third suborder elements pertain to bottom composition (eg. peat, sand, silt, etc.).

PHYSIOGRAPHY

The physiographic province file is based on Fenneman (1938) with his provinces as first order region (Table 3). The Applachian Highlands would be an example of a first order "physiographic region", with the Blue Ridge Mountains as an example of a first suborder "province" and Pisgah Ridge as a second order "subprovince." "Subprovinces" are distinctive features indicated on topographic maps or hydrographic charts. County and state of the natural area constitute the second suborder. Latitude-longitude of natural area is the third order with distance/direction from a permanent landmark the third suborder.

DEVELOPMENT AND APPLICATION OF SYSTEM

The making of a classification system for all biotic and abiotic features for our Natural Heritage is a tremendously complicated task. Progress has been made during the past 5 years on the development of a natural area classification. Much refining of the system remains to be done. This Natural Area Classification System has been or is being used or applied to approximately 150 Natural Areas in the southeastern United States--from Florida and Alabama north to West Virginia and Virginia, but mostly in the Carolinas.

The Natural Areas include all 15 vegetation systems; the estuarine, lacustrine, riverine, and palustrine aquatic and wetland systems; the alfisols, entisols, histosols, inceptisols, spodosols, and ultisols among the soil orders; the ultrabasic, basic, intermediate, acid, calcareous, ferruginous, carbonaceous, and salinaceous rock classes; and a wide variety of climatic, topographic, and hydrographic features in the Coastal Plain, Piedmont, Blue Ridge, Valley and Ridge, and Cumberland and Alleghany Mountain and Plateau Provinces.

Most of the data have been collected and the reports have been made by members of the plant ecosystematics classes at the University of North

Carolina at Chapel Hill or by natural area research associates sponsored by the Highlands Biological Station during the summers of 1974 and 1975. The summary reports resulting from this work will be similar to the Patsy Pond presentation (Appendix A). These reports will soon be available to conservationists, ecologists, taxonomists, and local, state, regional, and Federal agencies through a Natural Areas Inventory publication for the southeastern United States.

Application and use of this classification system for basic inventory of species, community, and habitat diversity (through Phase II--Appendix B) will provide the standardized baseline data and fundamental information for:

1. Conservation of species, community, and habitat diversity.
2. Ecological characterization of species, communities, and habitats.
3. Predictive system for species, communities, and habitats (what is where and under which conditions).
4. Perspective in species biology studies (endangered and threatened), community analyses, and habitat significance.
5. Interpretation of origin, migration, and evolution of species, floras, faunas, and communities.
6. Integrative classifications of many types (ie. map systems, habitat productivity, and trout streams).
7. Decisions on land use, impact evaluation, and management problems of many types.
8. Research foundation for applied and advanced problems in many fields of endeavor (eg. hydrology, pedology, habitat cover, food productivity, etc.).

NATURAL AREA INVENTORY FLOW SCHEME

A. Literature and Reports pertinent to Area (See Appendix B for detail).

Evaluation - reconnaissance - evaluation.

B. Onsite description and basic inventory.

Evaluation.

C. Conservation/acquisition of areas.

Protection and management.

D. Heritage Research.

Detailed ecological analyses, productivity studies, soils mapping, hydrologic measurements, etc..

CONCLUSIONS

This is an open ended system that can be done as thoroughly as the time and experience of the investigator will permit. The system can be coded for data banking. Natural areas in a conservation system, or those being proposed, should not be continually investigated for the same thing. The information gathered about the region should be made available to subsequent investigators so that new field data, resulting from each inventory, can be added to the data bank. All taxa should be documented once, not eliminated by eager biologists collecting in each and every visit to an area. An application product of this natural area classification system is presented, in part, in Appendix A and an ecological characterization of a rare species is given in Appendix C.

1. Any comprehensive natural area inventory should include the total biotic and abiotic (habitat) diversity.

2. Any standardization scheme for natural area inventories should include vegetational (with faunistic components), climatic, pedologic, geologic, hydrologic, and topographic data by province.

3. An acceptable standard natural area inventory system should have each character state properly circumscribed for each entry, at each hierarchical level, so that future studies and analyses will be comparable and correlative.

4. The Natural Area Classification System should be made as compatible as possible with present classification systems for vegetation, climate, soils, geology, hydrology, topography, hydrography, and physiographic provinces.

LITERATURE CITED

Cowardin, L. M., V. Carter, F. C. Golet and E. T. LaRoe. 1976. Interim Classification of Wetlands and Aquatic Habitats of the United States. U. S. Fish and Wildl. Serv. 109 pp.

Fenneman, N. M. 1938. Physiography of the Eastern United States. New York: McGraw-Hill Book Co., Inc.

Goode, J. P. and E. B. Espenshade, Jr. 1950. Goode's School Atlas. Rand McNally and Co., New York.

Radford, A. E. 1976. Ecosystematics Lab Manual. Chapel Hill: Univ. of North Carolina Student Stores. 289 pp.

Soil Survey Staff. 1975. Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys. Soil Conserv. Serv., U. S. Dept. Agric. Agric. Handbook 436. 745 pp.

APPENDIX A

PATSY POND NATURAL AREA[1]

Carteret County, North Carolina; 0.5 miles (0.8 Km) due n of NC 24, 12 mi. (19.3 Km) se Swansboro 34°43'35"N, 76°57'44"W, Salter Path, N.C. 7 1/2', 1949 Carolinian Subprovince; Atlantic Coastal Plain; Coastal Plain
20' (6.1 m)
ca. 70 acres (28.3 ha)

Ownership and Administration: Croatan National Forest.
Land Use: Hunting, recreation, timber.
Danger to Integrity: Damage done to area by vehicles.
Public Sensitivity: None known.

Priority Rating: (2) Appears to be nationally significant; (b) Site is in some jeopardy.
Reasons for Priority Rating: Area offers excellent examples of plant communities and zonation. Many rare and endangered or threatened plants of North Carolina are found here: *Eleocharis robbinsii*, *Litsea aestivalis*, *Ludwigia linifolia*, *Myriophyllum laxum*, *Polygonella articulata*, *Polygonum hirsutum*, *Rhynchospora inundata*, *Utricularia olivacea*. Moreover, a plant new to the state of North Carolina occurs here--*Sagittaria isoetiformis*. The area is also unique geologically.
Recommendations for Management: Area should be maintained as a natural area. Some periodic control burning should be done to keep zonation as is. Vehicular traffic (including motorcycles) should be stopped.

Data Sources: None.
Scientific References: None. See general references.
Documentation and Authentication: Specimens deposited in the NCU Herbarium by R. David Whetstone and Deborah Otte in 1976. Area analyzed in the fall of 1976. Complete documentation available from authors.

I. VEGETATION:
- A5. WOODLAND SYSTEM
  - AA6. *SILICEOUS WOODLAND*. B. pine-oak-heath ridge and flats; BB. *coniferales-fagales-ericales*. C. *Pinus palustris-Quercus laevis-Gaylussacia*; CC. *Pinus palustris-Quercus laevis-Gaylussacia spp.*
- A4. SCRUB-SHRUB SYSTEM
  - AA6. *SILICEOUS SHRUBS*. B. shrub zone; BB. *ericales*, *laurales-ericales*. C. *Cyrilla racemiflora, Litsea aestivalis*; CC. *Litsea aestivalis-Lyonia lucida*.
- A3. GRASS SYSTEM
  - AA6. *SILICEOUS GRASSES*. B. grass zone; BB. *poaceous*. C. *Andropogon scoparius*; CC. *Andropogon scoparius*.

---

[1] Contributed by Deborah Otte and R. David Whetstone, Department of Botany, University of North Carolina at Chapel Hill.

A10. MARSH HERB SYSTEM

AA1. *FRESH MARSH PERENNIALS*, AA5. *PEAT PERENNIALS*. B. mixed herb zone; BB. *mixed herbs*. C. *mixed herbs*; CC. *mixed herbs*.

A11. MARSH GRASS SYSTEM

A5. *PEAT GRASSES*. B. panic grass marsh; BB. *poaceous*. C. *Panicum hemitomon*; CC. *Panicum hemitomon*.

A8. VASCULAR AQUATIC SYSTEM[2]

AA1. *FRESH WATER GRASSES*, AA1. *FRESH WATER HERBS*. B. Spikerush bed (in some ponds a beakrush bed), B. panic grass bed, B. bladderwort mat, B. water milfoil bed, B. nymphoides bed, B. spatter-dock bed, B. water-lily bed; BB. *cyperaceous*, BB. *poaceous*, BB. *scrophulariales*, BB. *haloragales*, BB. *gentianales*, BB. *nympheales*. C. *Eleocharis equisetoides (Rhynchospora inundata)*, C. *Panicum hemitomon*, C. *Utricularia olivacea*, C. *Myriophyllum laxum*, C. *Nymphoides cordata*, C. *Nuphar luteum*, C. *Nymphaea odorata*; CC. *Eleocharis equisetoides (Rhynchospora inundata)-Nuphar luteum*, CC. *Panicum hemitomon*, CC. *Utricularia olivacea*, CC. *Myriophyllum laxum*, CC. *Nymphoides cordata*, CC. *Nuphar luteum*, CC. *Nymphaea odorata*.

II. CLIMATE: A. Mesothermal; AA. Lower Austral. B. Av. Max. 80°F, Av. Min. 45°F; BB. Mean annual precipitation 48" (122 cm). C. Freeze-free days 240; CC. Hydric to very dry-xeric.

III. SOILS: A. Entisol; AA. Psamment. B. Quartzipsamment; BB. Typic quartzipsamment, BB. Aquic quartzipsamment. C. Thermic, uncoated typic quartzipsamment, C. Thermic, uncoated aquic quartzipsamment; CC. Leon. A. Histosol; AA. Fibrist, AA. Saprist. B. Medifibrist, B. Sphagnofibrist, B. Medisaprist; BB. Typic medifibrist, BB. Limnic sphagnofibrist, BB. Limnic medisaprist. C. Thermic typic medifibrist, C. Sandy, coprogenous, euic, thermic limnic sphagnofibrist, C. Coprogenous, euic, thermic limnic medisaprist; CC. Peat, CC. Muck.

IV. GEOLOGY: A. Pleistocene sediments; AA. Flanner Beach Formation. B. Siliceous; BB. Clastic. C. Siliceous sands; CC. Silicon dioxide and ferruginous oxides.

V. HYDROLOGY: A. Lacustrine; AA. Littoral. B. Fresh; BB. Acidic. C. Seasonally to permanently flooded; CC. Clear.

VI. TOPOGRAPHY: A. Chowan terrace; AA. Patsy Pond Area. B. Old beach ridge system; BB. Sloping sand ridges, BB. Sand flats, BB. Seepage zone. C. North, east, south, west exposure; CC. Gently sloping and undulating to flat.

VII. HYDROGRAPHY: A. Broad Creek & Sanders Creek; AA. Patsy Pond and associated ponds. B. Naturally impounded ponds; BB. Eroded seepage slope and pond zones of varying water depths and substrates. C. Not applicable; CC. Muck, peat, sand.

DISCUSSION

The Patsy Pond Natural Area is a series of naturally impounded ponds on the Outer Coastal Plain of North Carolina. These ponds, the largest being Patsy Pond, support a unique assemblage of plants, exhibit excellent plant zonation, and represent interesting geologic features.

---

[2] VASCULAR AQUATIC SYSTEM -- includes emergent, submergent, or floating-leaved plants.

These ponds occur in an area which is an old beach ridge system of Pleistocene age. It is part of the Newport sand member of the Flanner Beach Formation. The Newport sands consist primarily of well-sorted sands believed to constitute barrier deposits emplaced on the downdrift side of an ancestral Neuse River (Mixon and Pilkey 1976). Near the study area, these sands overlie a layer of bluish-gray, clayey sand and abundant molluscan and ostracode fauna (indicative of Pleistocene age). The study site seems to be on an erosional slope of a broad sand ridge. Wind, sheet, and stream erosion have produced very gently sloping sand ridges and sand flats. These streams flow into either the West Prong of Broad Creek or the East Prong of Sanders Creek. The ponds appear to be products of natural impounding of old streams.

The vegetation of the area provides excellent examples of community types and their zonation. Definite relationships exist between these community types, and their substrates, and their moisture (Table 4).

A noteworthy feature is the occurrence of the Mixed Herb Community Type, a unique zone bordering these ponds. This zone varies from mesic sand to wet-hydric peat. The sandy areas are associated with openings in the Scrub-Shrub System border. We believe that fire has opened up these sandy areas by burning the Scrub-Shrub, and the accumulated peat from the soil surface. A broad overlap of species occurs from mesic to wet-hydric, and from sand to peat. Drosera capillaris, Centella asiatica, and Panicum spretum exhibit this type of variation. Others appear to be restricted to microedaphic features. Lycopodium appressum is restricted to the sandy areas whereas Eriocaulon and Eupatorium recurvans occur only over peat. The wetter areas, which are more resistant to burning, conceivably are seed reservoirs for herbs associated with this Community Type. Several noteworthy species that occur here are listed under Marsh Herb System (Table 5).

In addition, the area harbors a complex of plants referrable to Ilex cassine. Infraspecific taxa (Radford 1968) have been recognized as species by some authors (eg. Ilex myrtifolia Walter). Both varieties (Radford 1968) occurring here are distinctive, however, many intermediates exist.

The conservation of Patsy Pond Natural Area is quite justified. The general reasons are:

1) the presence of several endangered and threatened species (Table 5);

2) the presence of a unique assemblage of plants (ie. Mixed Herb Community Type);

3) the presence of unique geological features (ie. natural ponds on the Outer Coastal Plain of North Carolina which are not Carolina Bays);

4) the historical significance of the area as perhaps being a Neuse River Paleochannel (Mixon and Pilkey 1976);

5) and the added feature of the natural area as an "outdoor classroom" for taxonomical, ecological, geological, and pedological studies.

Certainly Patsy Pond Natural Area constitutes a real and valuable national, natural heritage which deserves recognition and conservation for both ourselves and for our posterity.

Table 4. Community Types: Edaphic and Moisture Relations

Vegetation System	Community Types	Soil Family	Water	Moisture Class
Vascular Aquatic	*Utricularia olivacea* *Myriophyllum laxum* *Nuphar luteum* *Nymphaea odorata* *Nymphoides cordata* *Eleocharis equisetoides-Nuphar luteum* *Rhynchospora inundata-Nuphar luteum*	Coprogenous, euic, thermic limnic medisaprist	60 cm to 2.5 m deep (probably does get deeper)	Hydric
	Panicum hemitomon	Euic, thermic typic medifibrist to sandy, coprogenous, euic, thermic limnic sphagnofibrist	5-20 cm deep	Hydric
Marsh Grass	*Panicum hemitomon*	Sandy, coprogenous, euic, thermic limnic sphagnofibrist	Saturated, but usually not in standing water	Wet-hydric to hydric
Marsh Herb	Mixed herbs	Euic, thermic typic medifibrist or thermic, uncoated aquic quartzipsamment	Saturated, water table only 15 cm down	Wet-hydric to mesic
Grass	*Andropogon scoparius*	Thermic, uncoated typic quartzipsamment	Water table 45 cm down	Dry-mesic
Scrub-Shrub	*Cyrilla racemiflora-Lyonia lucida-Vaccinium atrococcum*	Thermic, uncoated typic quartzipsamment	Water table 90 cm down	Dry-mesic
	Litsea aestivalis-Lyonia lucida	Thermic, uncoated typic quartzipsamment	Water table 90 cm down	Dry-mesic
Woodland	*Pinus palustris-Quercus laevis-Gaylussacia*	Thermic, uncoated typic quartzipsamment	Water table much further down	Very dry-xeric

TABLE 5. Endangered and Threatened Species

SPECIES	ENDANGERED OR THREATENED STATUS[a]	VEGETATION SYSTEM
Burmannia biflora	Infrequent throughout	Marsh herb
Eleocharis robbinsii	Endangered disjunct	Marsh herb
Eragrostis elliottii	Infrequent peripheral	Woodland
Litsea aestivalis	Endangered peripheral	Scrub-shrub
Ludwigia linifolia	Endangered disjunct	Marsh herb
Myriophyllum laxum	Threatened throughout	Vascular Aquatic
Nymphoides cordata	Infrequent peripheral	Vascular Aquatic
Panicum spretum	Infrequent peripheral	Marsh herb
Polygonella articulata	Endangered disjunct	Woodland
Polygonum hirsutum	Endangered throughout	Marsh herb
Rhynchospora inundata	Infrequent throughout	Vascular Aquatic
Sagittaria isoetiformis	Threatened peripheral	Vascular Aquatic
Utricularia olivacea	Threatened throughout	Vascular Aquatic

[a] Endangered and threatened categories are as follows: Endangered-endemic, throughout, disjunct; Threatened-endemic, throughout, disjunct; Endangered peripheral; Threatened peripheral; Infrequent-endemic, throughout, peripheral.

I.A5. WOODLAND SYSTEM
I.AA6. SILICEOUS WOODLAND

I.B. pine-oak-heath ridge and flats
I.BB. *coniferales-fagales-ericales*

I.CC. *Pinus palustris-Quercus laevis-Gaylussacia spp.*
I.C. *Pinus palustris-Quercus laevis-Gaylussacia*

II. CLIMATE: A. Mesothermal; AA. Lower Austral. B. Av. Max. 80°F, Av. Min. 45°F; BB. Mean annual precipitation 48 inches (121.9 cm). C. Freeze-free days 240; CC. Very dry-xeric.

III. SOILS: A. Entisol; AA. Psamment. B. Quartzipsamment; BB. Typic quartzipsamment. C. Thermic, uncoated typic quartzipsamment; CC. Leon.
Topsoil: 0-86 cm, light gray, fine to medium sand, pH 4.0.
Subsoil: dark reddish brown, fine to medium coated sand, pH 4.0 (hardpan).
Very dry-xeric; very strongly acid; sandy.

IV. GEOLOGY: A. Pleistocene sediments; AA. Flanner Beach Formation. B. Siliceous; BB. Clastic. C. Siliceous sands; CC. Silicon dioxide and ferruginous oxides.

VI. TOPOGRAPHY: A. Chowan terrace; AA. Patsy Pond Area. B. Old beach ridge system; BB. Gently sloping sand ridges, sand flats. C. North, east, south, west exposure; CC. Gently sloping and undulating to flat.

I. CANOPY ANALYSIS:

Species	I.V.	Relative Density (%)	Relative Dominance (%)	Relative Frequency (%)
Pinus palustris	189.98	73.44	77.73	38.81
Quercus laevis	63.96	20.31	19.84	23.81
Q. virginiana	23.98	3.13	1.80	19.05
Q. laurifolia	22.82	3.13	0.64	19.05

Based on 16 quarterpoints; d = 19.02 ft. (5.8 m); 120.41 individuals/acre (48.7 individuals/ha).

Also Present: *Ilex opaca*, *Liquidambar styraciflua*, *Pinus taeda*, *Quercus* x *blufftonesis*, *Q. falcata*, *Q. margaretta*, and *Sassafras albidum*.

I. SUBCANOPY AND SHRUB ANALYSIS:

Species	3 m^2 Releves (Cover. Sociability)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gaylussacia dumosa	5.4	1.4		1.3	1.3	3.3	4.3	3.3	2.3	2.3	1.3	5.3	2.3	5.3	2.3	2.3
G. frondosa				5.3	3.3	1.3	3.3	1.3	1.3	1.3	3.3	3.3		1.3		5.3
Ilex glabra					2.3		2.3									
Lyonia mariana	2.1					1.3					2.3				1.3	
Myrica cerifera var. pumila				2.3	1.3	2.3	2.3	5.3	5.3	2.3	1.3	1.1	1.3	1.3	1.3	2.3
Rhus copallina					+0.1											
Vaccinium crassifolium																2.4
V. tenellum																1.2
V. vacillans		+0.1														

Also present: Castanea pumila var. ashei, Crataegus sp., Hyperimuc reductum, Lyonia lucida, Myrica heterophylla, and Vaccinium arboreum.

I. HERB ANALYSIS:

Species	1 m^2 Releves (Cover. Sociability)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Aristida stricta	4.3	5.3	1.3	1.3	2.3		3.3	2.3	2.3	2.3	4.3	2.3	1.3	2.3	1.3	3.3
Aster linariifolius								1.1								
Carphephorus bellidifolius										1.2		+0.1				
Heterotheca adenolepia			1.1						1.1	1.1						
Polygonella articulata	+0.1	1.1														
Sericocarpus bifoliatus							1.1									
Tragia urens					+0.1											

Also Present: Andropogon scoparius, A. virginicus, Cirsium repandum, Cnidoscolus stimulosus, Eragrostis elliottii. Eupatorium recurvans, Gnaphalium obtusifolium, Lachnocaulon minus, Liatris secunda, Monotropa uniflora, Panicum portoricense, Pteridium aquilinum, Sporobolus poirettii, Stipulicida setacea, and Tridens flavus.

I.A4. SCRUB-SHRUB SYSTEM I.B. shrub zone
I.AA6. SILICEOUS SHRUBS I.BB. ericales OR laurales-ericales

I.CC. Cyrilla racemiflora-Lyonia lucida-Vaccinium atrococcum
I.C. Cyrilla racemiflora

OR

I.CC. Litsea aestivalis-Lyonia lucida
I.C. Litsea aestivalis

II. CLIMATE: A. Mesothermal; AA. Lower Austral. B. Av. Max. 80°F, Av. Min. 45°F; BB. Mean annual precipitation 48 inches (121.9 cm). C. Freeze-free days 240; CC. Dry-mesic.

III. SOILS: A. Entisol; AA. Psamment. B. Quartzipsamment; BB. Typic quartzipsamment. C. Thermic, uncoated typic quartzipsamment; CC. Leon.
Topsoil: 0-70 cm, light gray, fine to medium sand, pH 3.9.
Subsoil: dark reddish brown, fine to medium coated sand, pH 3.9 (hardpan).
Dry-mesic; very strongly acid; sandy.

IV. GEOLOGY: A. Pleistocene sediments; AA. Flanner Beach Formation. B. Siliceous; BB. Clastic. C. Siliceous sands; CC. Silicon dioxide and ferruginous oxides.

VI. TOPOGRAPHY: A. Chowan terrace; AA. Patsy Pond Area. B. Old beach ridge system; BB. Seepage zone. C. North, east, south, west exposure; CC. Gently sloping.

I.A3. GRASS SYSTEM I.B. grass zone
I.AA6. SILICEOUS GRASSES I.BB. poaceous

I.C. Andropogon scoparius
I.CC. Andropogon scoparius

II. CLIMATE: A. Mesothermal; AA. Lower Austral. B. Av. Max. 80°F, Av. Min. 45°F; BB. Mean annual precipitation 48" (121.9 cm) C. Freeze-free days 240; CC. Dry-mesic.

III. SOILS: A. Entisol; AA. Psamment. B. Quartzipsamment; BB. Typic quartzipsamment. C. Thermic, uncoated typic quartzipsamment; CC. Leon.
Topsoil: 0-70 cm, light gray, fine to medium sand, pH 3.9.
Subsoil: dark reddish brown, fine to medium coated sand, pH 3.9 (hardpan).
Dry-mesic; very strongly acid; sandy.

IV. GEOLOGY: A. Pleistocene sediments; AA. Flanner Beach Formation. B. Siliceous; BB. Clastic. C. Siliceous sands; CC. Silicon dioxide and ferruginous oxides.

VI. TOPOGRAPHY: A. Chowan terrace; AA. Patsy Pond Area. B. Old beach ridge system; BB. Sand flat. C. North, east, south, west exposure; CC. Gently sloping.

I. SHRUB ANALYSIS:

Species	3 m² Releves (Cover. Sociability)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Cyrilla racemiflora	4.3	5.3	5.3	5.3	5.3	4.3	5.3	3.3	2.3					
Ilex cassine var. *myrtifolia*			2.3	2.3			1.3					1.3		
I. glabra							+0.3			+0.3				
Litsea aestivalis										1.3	4.3	5.3		3.3
Lyonia lucida	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	1.3	4.3	5.3	3.3	4.3
Myrica cerifera var. *cerifera*					+0.3									
Sorbus arbutifolia							2.3							
Vaccinium atrococcum	3.3		2.3		2.3	3.3	2.3	3.3	2.3	5.3			5.3	3.3

Also present: *Acer rubrum*, *Arundinaria gigantea*, *Baccharis halimifolia*, *Cephalanthus occidentalis*, *Illex cassine* var. *cassine*, *I. coriacea*, *I. opaca*, *Lachnocaulon minus*, *Liquidambar styraciflua*, *Lyonia mariana*, *Magnolia grandiflora*, *M. virginiana*, *Myrica heterophylla*, *Persea borbonia*, *Pinus serotina*, *Rhus copallina*, *Salix caroliniana*, *Sarracenia flava*, *Smilax glauca*, *S. laurifolia*, *S. rotundifolia*, *Vaccinium crassifolium*, and *Woodwardia virginica*.

I. HERB ANALYSIS:

Species	1 m^2 Releves (Cover. Sociability)							
	37	38	39	40	41	42	43	44
Andropogon scoparius	4.2	5.2	5.2	4.2	3.2	5.2	5.2	5.2
A. virginicus								0.3
Centella asiatica	3.5	2.5	1.5	2.5	2.5	2.5	2.5	4.5
Drosera capillaris	0.1	0.1	0.1	0.1	0.1			
D. intermedia		0.1	0.1	0.1	1.1			
Eleocharis sp.	3.2	1.2		1.2	2.2			
Panicum spretum								1.3
Polygala lutea							1.1	
Rhynchospora wrightiana						1.2	1.2	1.2
Rhexia mariana					0.1			
Xyris caroliniana	0.1	0.1	0.1		0.1			

Also present: *Eupatorium recurvans*.

I.A10. MARSH HERB SYSTEM
I.AA1. *FRESH MARSH PERENNIALS*
OR
I.AA5. *PEAT PERENNIALS*

I.B. mixed herb marsh
I.BB. *mixed herbs*

I.CC. *Mixed herbs*
I.C. Mixed herbs

II. CLIMATE: A. Mesothermal; AA. Lower Austral. B. Av. Max. 80°F, Av. Min. 45°F; BB. Mean annual precipitation 48". C. Freeze-free days 240; CC. Wet-hydric to mesic.

III. SOILS: A. Entisol; AA. Psamment. B. Quartzipsamment; BB. Aquic quartzipsamment. C. Thermic, uncoated aquic quartzipsamment; CC. Leon. A. Histosol; AA. Fibrist. B. Medifibrist; BB. Typic medifibrist. C. Euic, thermic typic medifibrist; CC. Peat.

Topsoil: 0-40 cm, light gray, fine to medium sand, pH 3.9.
0-16 cm, peat, pH 4.0.
Subsoil: dark reddish brown, fine to medium coated sand, pH 3.9 (hardpan).
light gray, fine to medium sand.

Mesic to wet-hydric; very strongly acid, sandy, peat.

IV. GEOLOGY: A. Pleistocene sediments; AA. Flanner Beach Formation. B. Siliceous; BB. Clastic. C. Siliceous sands; CC. Silicon dioxide and ferruginous oxides.

V. HYDROLOGY: A. Lacustrine; AA. Littoral. B. Fresh; BB. Acidic. C. Seasonally flooded; CC. Clear.

VI. TOPOGRAPHY: A. Chowan Terrace; AA. Patsy Pond Area. B. Old beach ridge system; BB. Seepage zone. C. North, east, south, west exposure; CC. Gently sloping.

VII. HYDROGRAPHY: A. Broad Creek & Sanders Creek; AA. Patsy Pond and associated ponds. B. Naturally impounded ponds; BB. Eroded seepage slope. C. Not applicable; CC. Peat, sand.

I. HERB ANALYSIS:

Species	1m² Releves (Cover. Sociability)																		
	DEEP PEAT							INUNDATED PEAT					SPARSE SPHAGNUM			SAND			
	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Andropogon scoparius								1.2	+0.2	2.2	1.2	1.2				1.2	1.2	1.2	3.2
A. virginicus	+0.3																		
Burmannia biflora																			+0.1
B. capitata	+0.1																		1.1
Centella asiatica	+0.5		+0.5		1.5			3.5	1.5	1.5	1.5		5.5		5.5	4.5	5.5	5.5	5.5
Drosera capillaris																1.1	1.1	1.1	1.1
D. intermdeia	+0.1	1.1				2.1	3.1					+0.1	+0.1	+0.1		+0.1	1.1	1.1	
Eleocharis sp.									3.2		2.2	3.2							
Eriocaulon sp.	3.2	3.2	3.2	+0.2	5.2	5.2	5.2	+0.2	1.2	2.2	1.2								
Eupatorium recurvans								2.1											
Juncus abortivus								5.1	1.1	3.1	3.1	+0.1			+0.1				
J. dichotomus													+0.1		+0.1				
Lachnanthes caroliniana		2.1			2.1														
Ludwigia linifolia										+0.1	1.1								
Lycopodium appressum		+0.5														2.5	2.5	2.5	2.5
Nymphoides cordata												1.2							
Panicum hemitomon	2.5	1.5			1.5									1.5	+0.5				
P. portoricense		+0.3									1.3	+0.3	2.3						
P. spretum	+0.3	2.3	2.3						1.3	2.3				1.3	1.3	1.3	2.3	1.3	2.3
P. virgatum				1.1		2.1	2.1								+0.1				
Polygala cymosa												1.1							
Proserpinaca pectinata	2.1	1.1	2.1	+0.1	3.1	3.1	5.1			2.1	3.1	2.1			+0.1				+0.1
Rhynchospora wrightiana	+0.2												5.2						
Rhexia mariana	1.1	+0.1	1.1					1.1		+0.1	1.1								
Scleria reticularis	+0.2													1.1	+0.1				
Tridens flavus																			2.2
Utricularia juncea								2.1	1.1	1.1	1.1	1.1							
U. olivacea								5.1	5.1	1.1	1.1	1.1							
U. purpurea										+0.1		+0.1							
Viola lanceolata	2.1					1.1										+0.1	+0.1	+0.1	+0.1
Xyris caroliniana	+0.1								+0.1	1.1	1.1								

Also Present: *Agalinis purpurea*, *Bartonia paniculata*, *Erigeron vernus*, *Eriocaulon compressum*, *Eupatorium capillifolium* var. *capillifolium*, *Hypericum cistifolium*, *Lycopodium carolinianum*, *Nyssa sylvatica* var. *biflora*, *Panicum verrucosum*, *Pogonia ophioglossoides*, *Polygala lutea*, *Polygonum hirsutum*, *Scirpus cyperinus*, *Solidago fistulosa*, *S. tenuifolia*, and *Sphagnum sp.*

I.A11. MARSH GRASS SYSTEM
I.AA5. PEAT GRASSES

I.B. panic grass marsh
I.BB. poaceous

I.CC. Panicum hemitomon
I.C. Panicum hemitomon

II. CLIMATE: A. Mesothermal; AA. Lower Austral. B. Av. Max. 80°F, Av. Min. 45°F; BB. Mean annual precipitation 48". C. Freeze-free days 240; CC. Wet-hydric to hydric.

III. SOILS: A. Histosol; AA. Fibrist. B. Sphagnofibrist; BB. Limnic sphagnofibrist. C. Sandy, coprogenous, euic, thermic limnic sphagnofibrist; CC. Peat.
Topsoil: 2.8 m, peat, pH 5.5.
Subsoil: light gray, fine to medium sand.
Wet-hydric to hydric; acid; sandy peat.

V. HYDROLOGY: A. Lacustrine; AA. Littoral. B. Fresh; BB. Acidic. C. Seasonally flooded; CC. Clear.

VII. HYDROGRAPHY: A. Broad Creek & Sanders Creek; AA. Patsy Pond and associated ponds. B. Naturally impounded ponds; BB. Hammock. C. Not applicable; CC. Peat.

I. CANOPY: One transgressive of Pinus serotina.

I. HERB ANALYSIS: Observation only. Cover is almost 100% Panicum hemitomon. Also Present: Pogonia ophioglossoides and Utricularia spp.

I.A8. VASCULAR AQUATIC SYSTEM
I.AA1. FRESH WATER GRASSES

I.B. spikerush (or beakrush) bed
I.BB. cyperaceous-nymphaeales

I.CC. Eleocharis equisetoides-Nuphar luteum
I.C. Eleocharis equisetoides

OR

I.CC. Rhynchospora inundata-Nuphar luteum
I.C. Rhynchospora inundata

II. CLIMATE: A. Mesothermal; AA. Lower Austral. B. Av. Max. 80°F, Av. Min. 45°F; BB. Mean annual precipitation 48". C. Freeze-free days 240; CC. Hydric.

III. SOILS: A. Histosol; AA. Saprist. B. Medisaprist; BB. Limnic medisaprist. C. Coprogenous, euic, thermic limnic medisaprist; CC. Muck.
Topsoil: muck, pH 5.5.
Subsoil: sand.
Hydric; acidic; muck.

V. HYDROLOGY: A. Lacustrine; AA. Littoral. B. Fresh; BB. Acidic. C. Permanently flooded; CC. Clear.

VII. HYDROGRAPHY: A. Broad Creek & Sanders Creek; AA. Patsy Pond and associated ponds. B. Naturally impounded ponds; BB. Pond zone with water depth of 60 cm. C. Not applicable; CC. Muck.

I. AQUATIC ANALYSIS: follows.

I.A8. VASCULAR AQUATIC SYSTEM
I.AA1. FRESH WATER GRASSES

I.B. panic grass bed
I.BB. poaceous

I.CC. Panicum hemitomon
I.C. Panicum hemitomon

II. CLIMATE: A. Mesothermal; AA. Lower Austral. B. Av. Max. 80°F, Av. Min. 45°F; BB. Mean annual precipitation 48". C. Freeze-free days 240; CC. Hydric.

III. SOILS: A. Histosol; AA. Fibrist. B. Medifibrist to sphagnofibrist; BB. Typic medifibrist to limnic sphagnofibrist. C. Euic, thermic typic medifibrist to sandy, coprogenous, euic, thermic limnic sphagnofibrist; CC. Peat.
Topsoil: 0-3 m, peat, pH 5.5.
Subsoil: sand.
Hydric; acidic; peat.

V. HYDROLOGY: A. Lacustrine; AA. Littoral. B. Fresh; BB. Acidic. C. Permanently flooded; CC. Clear.

VII. HYDROGRAPHY: A. Broad Creek & Sanders Creek; AA. Patsy Pond and associated ponds. B. Naturally impounded ponds; BB. Pond zone with water depth of 5-20 cm. C. Not applicable; CC. Peat.

I.A8. VASCULAR AQUATIC SYSTEM
I.AA1. FRESH WATER HERBS

I.B. bladderwort mat OR watermilfoil bed OR nymphoides bed OR spatterdock bed OR water-lily bed*
I.BB. scrophulariales OR haloragales OR gentianales OR nymphaeales

I.CC. Utricularia olivacea OR Myriophyllum laxum OR Nymphoides cordata OR Nuphar luteum OR Nymphaea odorata
I.C. Utricularia olivacea Myriophyllum laxum Nymphoides cordata Nuphar luteum Nymphaea odorata

II. CLIMATE: A. Mesothermal; AA. Lower Austral. B. Av. Max. 80°F, Av. Min. 45°F; BB. Mean annual precipitation 48". C. Freeze-free days 240; CC. Hydric.

III. SOILS: A. Histosol; AA. Saprist. B. Medisaprist; BB. Limnic medisaprist. C. Coprogenous, euic, thermic limnic medisaprist; CC. Muck.

V. HYDROLOGY: A. Lacustrine; AA. Littoral. B. Fresh; BB. Acidic. C. Permanently flooded; CC. Clear.

VII. HYDROGRAPHY: A. Broad Creek & Sanders Creek; AA. Patsy Pond and associated ponds. B. Naturally impounded ponds; BB. Pond zone with water depth of 60 cm - 2.5 m. C. Not applicable; CC. Muck.

I. AQUATIC ANALYSIS: follows.

*Combinations of these can also occur.

I. AQUATIC ANALYSIS:

Species	1 m^2 Releves (Cover. Sociability)																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Eleocharis equisetoides										+0.5		4.5	5.5	4.5	4.5	4.5	4.5
E. sp. (W 8754)	+0.2	+0.2															
Myriophyllum laxum	4.4	4.4															
Nuphar luteum						2.2		1.2	2.2			4.2	1.2	+0.2	+0.2	+0.2	+0.2
Nymphaea odorata	2.2	3.2	3.2	3.2													
Nymphoides cordata	5.2	+0.2															
Panicum hemitomon					5.5	2.5	5.5	5.5	3.5	5.5	5.5	1.5					
Utricularia olivacea	3.1	3.1															

Also Present: *Eleocharis robbinsii*, *Hydrocotyle* sp., *Pontederia cordata*, *Proserpinaca pectinata*, *Rhynchospora inundata*, *Sacciolepis striata*, *Sagittaria isoetiformis*, *Utricularia biflora*, *U. juncea*, *U. purpurea*, and *Xyris caroliniana*.

LITERATURE CITED

Fernald, M.L. 1950. Gray's Manual of Botany. 8th ed. American Book Co. New York.

Hardin, J.W., North Carolina Rare, Endangered and Threatened Plant Species List. North Carolina Museum of Natural History Bulletin (in preparation).

Mixon, R.B. and O.H. Pilkey. 1976. Reconnaissance geology of the submerged and emerged coastal plain province, Cape Lookout Area, North Carolina. Geological Survey Professional Paper 859. U.S. Government Printing Office, Washington, D.C.

Radford, A.E., V.H.E. Ahles and C.R. Bell. 1968. Manual of the Vascular Flora of the Carolinas. The University of North Carolina Press, Chapel Hill.

Small, J.K. 1972. Manual of the Southeastern Flora. 2 Vol. (facsimile reprint of the 1933 edition). Hafner Pub. Co., New York.

U.S.G.S. 1970. The National Atlas of the United States of America. U.S. Department of the Interior, Washington, D.C.

APPENDIX B.

NATURAL AREAS

PHASE I

A. LITERATURE - REPORTS

INFORMATION SYSTEM I	INFORMATION SOURCES I
I BIOTIC COMMUNITIES	
A. Vegetation System (Habit) AA. Vegetation Subsystem (Rock/water chemistry-habit) B. Community Cover Class BB. Community Class C. Community Cover Type CC. Community Type	Kuchler (1964) Vegetation Map Regional Forest Survey Maps State Vegetation Maps Pertinent local flora, fauna and vegetation studies and reports
II CLIMATOLOGY	
A. Climatic Regimes AA. Climatic Subregimes B. Temperature Zones; Av. Max. Min. BB. Moisture Zones; Av. Max. Min. C. Temperature Types (Frostfree Days) CC. Moisture Types (Community - Soil)	Climatic Atlas of the United States Climates of the States Climatic Data
III PEDOLOGY	
A. Soils Order AA. Soils Suborder B. Soils Great Group BB. Soils Subgroup C. Soils Family CC. Soils Series	National Atlas Maps State Soil Maps County Soil Surveys Pertinent local soil studies and reports
IV GEOLOGY	
A. Formation Age/System AA. Geologic Formation B. Rock Class (Chemistry) BB. Rock Subclass (Chemistry) C. Rock Type (Mineral Composition) CC. Rock Primary Mineral(s)	Geologic Map of the United States State Geologic Maps Local Geologic Surveys Pertinent local geologic studies and reports

INFORMATION SYSTEM I	INFORMATION SOURCES I
V HYDROLOGY A. Hydrologic System AA. Hydrologic Subsystem B. Water Class (Chemistry) BB. Water Subclass (Chemistry) C. Water Type (Hydroperiod) CC. Water Turbidity (Color)	Regional Runoff, Aquifer and Water Balance Maps Drainage Maps (State) Hydrologic Data
VI TOPOGRAPHY A. Major Landform AA. Natural Area Landform B. Topographic Feature (Origin) BB. Relief Feature C. Slope Exposure CC. Slope Degree	Regional Topographic Maps 1:250,000 Local Topographic Maps 1:62,500 & 1:24,000 Gemorphological studies and reports
VII HYDROGRAPHY A. Major Water Body or Landform AA. Natural Area Water Body B. Hydrographic Feature (Origin) BB. Relief Feature C. Current Type CC. Bottom (Composition)	Regional Hydrographic Charts Local Hydrographic Charts State Drainage Maps
VIII PHYSIOGRAPHY A. Region A. Province B. Subprovince BB. County, State C. Latitude, Longitude CC. Locality	National Atlas Fenneman, 1938 Local Topographic Maps Pertinent local geographic studies and reports

B. RECONNAISSANCE AND EVALUATION SUGGESTIONS

INFORMATION SYSTEM I	INFORMATION SOURCES I
I ENDANGERED & THREATENED SPECIES Endangered Endemic 10 Endangered Throughout 9 Endangered Disjunct 8 Threatened Endemic 7 Threatened Throughout 6 Threatened Disjunct 5 Endangered Peripheral 4 Threatened Peripheral 3 Infrequent Endemic 2 Infrequent Peripheral 1	International Lists Smithsonian List State Lists Field observation, determination and authentication
II BIOTIC AND ABIOTIC DIVERSITY Biotic Systems Pedologic Cover Classes Geologic Cover Types Hydrologic Species Topographic Hydrographic Excellent, 5; Good, 4; Average, 3; Mediocre, 2; Poor, 1.	Vegetation maps, studies and reports Pedologic maps, studies and reports Hydrologic maps, studies and reports Topographic maps, studies and reports Field observation, determination and authentication
III NATURAL FEATURES CONDITION Communities Hydrology Soils Topography Geology Hydrography Virgin or excellent, 5; Good, 4; Average, 3; Mediocre, 2; Poor, 1.	Pertinent reports and studies Field observation and determination
IV NATURAL FEATURES DISTRIBUTION Community Hydrology Pedology Topography Geology Hydrography Endemic, 5; Unique, 4; Infrequent, 3; Common, 2; Very Common, 1.	Vegetation maps, studies and reports Pedologic maps, studies and reports Geologic maps, studies and reports Hydrologic maps, studies and reports Topographic maps, studies and reports Hydrographic maps, studies and reports Field observation and determination
V HUMANISTIC FEATURES Aesthetic Value Scenic Value Scientific Value Historical Value Excellent, 5; Good, 4; Average, 3; Mediocre, 2; Poor, 1.	Field experience and reports Scientific reports Historical reports

INFORMATION SYSTEM I	INFORMATION SOURCES I
VI PRODUCTIVITY etc. Biomass Cover Food Breeding territory Excellent, 5; Good, 4; Average, 3; Mediocre, 2; Poor, 1.	

PHASE II

A. ON-SITE DESCRIPTION

(Basic Inventory)

INFORMATION SYSTEM II	INFORMATION SOURCES II (Identification & techniques)
I BIOTIC COMMUNITIES	Radford et al. 1976
A. Vegetation System (Habit)	Local or Regional Manual
AA. Vegetation Subsystem (Rock/water chemistry-habit)	Quarter Point and Releve
B. Community Cover Class	
BB. Community Class	
C. Community Cover Type	
CC. Community Type	
II CLIMATOLOGY	
A. Climatic Regimes	Climatic Atlas of the United States
AA. Climatic Subregimes	Climates of the States
B. Temperature Zones; Av. Max. Min.	Climatic Data
BB. Moisture Zones; Av. Max. Min.	
C. Temperature Types (Frostfree Days)	
CC. Moisture Types (Community - Soil)	
III PEDOLOGY	
A. Soils Order	"Soil Taxonomy", 1975
AA. Soils Suborder	"Soil Series of the United States, etc.", 1971
B. Soils Great Group	"Soil Survey Laboratory Methods, etc.", 1972
BB. Soils Subgroup	
C. Soils Family	
CC. Soils Series	

INFORMATION SYSTEM II	INFORMATION SOURCES II (Identification & techniques)
IV GEOLOGY A. Formation Age/System AA. Geologic Formation B. Rock Class (Chemistry) BB. Rock Subclass (Chemistry) C. Rock Type (Mineral Composition) CC. Rock Primary Mineral(s)	Geologic Map of the United States State Geologic Maps Local Geologic Surveys Pertinent local geologic studies and reports
V HYDROLOGY A. Hyrologic System AA. Hydrologic Subsystem B. Water Class (Chemistry) BB. Water Turbidity (Color) C. Water Type (Hydroperiod) CC. Water Turbidity (Color)	Regional Runoff, Aquifer and Water Balance Maps Drainage Maps (State) Hydrologic Data
VI TOPOGRAPHY A. Major Landform AA. Natural Area Landform B. Topographic Feature (Origin) BB. Relief Feature C. Slope Exposure CC. Slope Degree	Regional Topographic Maps 1:250,000 Local Topographic Maps 1:62,500 & 1:24,000 Geomorphological studies and reports
VII HYDROGRAPHY A. Major Water Body AA. Natural Area Water Body B. Hydrographic Feature (Origin) BB. Relief Feature C. Current Type CC. Bottom (Composition)	Regional Hydrographic Charts Local Hydrographic Charts State Drainage Maps
VIII PHYSIOGRAPHY A. Region AA. Province B. Subprovince BB. County, State C. Latitude, Longitude CC. Locality	National Atlas Fenneman, 1938 Local Topographic Maps Pertinent local geographic studies and reports

B. EVALUATION

(Use evaluation system in IB, Base final conclusions on "on-site" information and data).

PHASE III
CONSERVATION AND PROTECTION
(ACQUISITION and MANAGEMENT)

PHASE IV
HERITAGE ANALYSES & SYNTHESES

SPECIALTY STUDIES by TAXONOMISTS, ECOLOGISTS
CLIMATOLOGISTS, PEDOLOGISTS, GEOLOGISTS
HYDROLOGISTS, GEOGRAPHERS, EVOLUTIONISTS.

APPENDIX C

ECOLOGICAL ATLAS OF THREATENED & ENDANGERED SPECIES

1. GEUM RADIATUM Michaux

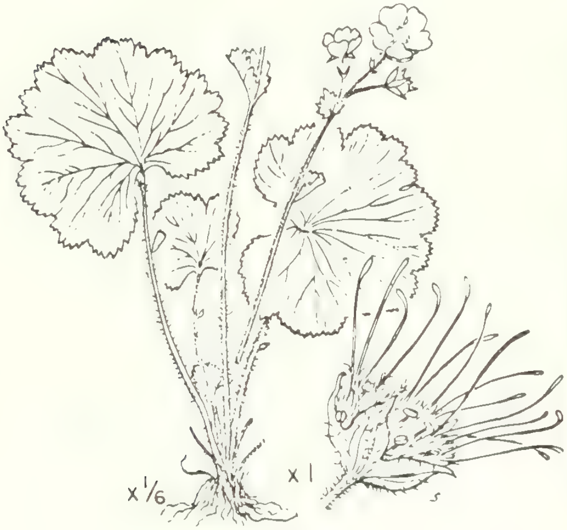
2. Rosaceae

3. Appalachian Avens, Geum, Avens

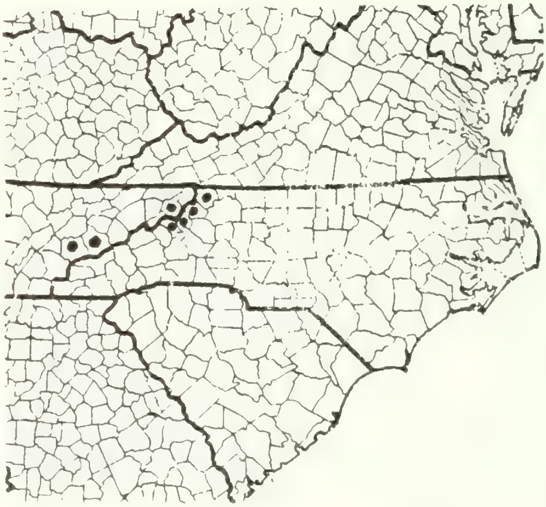
4. National -Endangered
NC - Endangered

5. Synonomy:
Sieversia radiata G. Don
Acomastylis radiata F. Bolle
Parageum radiatum Hara

6. Location of Type Specimen(s):
Museum National d'Histoire Naturelle (P)
Laboratoire de Phanerogamie
16 Rue Buffon
75005 Paris, France



7. Illustration



8. Distribution Map

9. Plant Habit Type:
Herb

10. Inhabitant Type:
Terrestrial

11. Life Span:
Perennial

12. Vegetative Phenophase:
May to September

13. Flowering Phenophase:
July to September

14. Fruiting Phenophase:
July to October

15. Distribution:

State:	County:
North Carolina	Ashe, Avery, Mitchell Watauga
Tennessee	Blount, Carter, Sevier

16. Latitude and Longitude:
(Total Range)
35° - 37°N
81° - 84°W

Contributed by S.W. Morgan, Botany Department, UNC - Chapel Hill. Documentation deposited in UNC Herbarium.
Information and documentation systems after Massey, J.R. and P.D. Whitson. 1977. Species Biology (Unpublished).

ECOLOGICAL ATLAS, *Geum radiatum*, p. 2

17. Vegetation (I):
    A. Grass System
    AA. Siliceous grass
    B. Grass zone
    BB. Poales
    C. Danthonia compressa
    CC. Oat grass-mixed forb

18. Climatology (II):
    A. Microthermal
    AA. Continental humid
    B. Canadian
    BB. Average rainfall
    C. Medium frostbound
    CC. Mesic to wet mesic

19. Pedology (III):
    A. Inceptisol
    AA. Umbrept
    B. Haplumbrept
    BB. Typic haplumbrept
    C. Coarse-loamy, mixed, mesic, typic haplumbrept
    CC. Burton

20. Geology (IV):
    A. Precambrian igneous and metamorphic
    AA. Horneblend gneiss
    B. Siliceous
    BB. N.A.
    C. Gneiss and schist
    CC. Feldspar, quartz; muscovite, chlorite horneblende

21. Topography (VI):
    A. Roan Mountain Ridge
    AA. Cloudland Trail Ridge
    B. Divide ridge
    BB. Broad ridge crest
    C. SE slope
    CC. Gentle slope (6-8°)

22. Physiography (VIII):
    A. Appalachian Highlands
    AA. Blue Ridge
    B. Roan Mountain Ridge
    BB. Mitchell County, North Carolina
    C. 36° 05' 40" N; 82° 08' 30" W
    CC. 7.75 mi. SW of Roan Mountain, Tennessee

23. Biotic Associates: *Rhododendron catawbiense*, *Leiophyllum buxifolium*, *Houstonia serpyllifolia*, *Danthonia compressa*, *Deschampsia flexuosa*.

24. Succession: Lithosere; Middle successional stage.

25. Ownership-Administration: Pisgah National Forest.

26. Land Use Designation: National Forest Recreation Area.

27. Dangers to Integrity: Tourists digging up plants.

28. Management Recommendations: The *Rhododendron catawbiense* seedlings must be kept out of the grassy areas where *Geum radiatum* grows. Spruce and fir must be kept from shading out *Geum radiatum*.

Note: Items 17-28 apply to only one population of *Geum radiatum* on Roan Mountain.

Session III
Ecological Relationships

THE RELATIONSHIP OF TERRESTRIAL VERTEBRATES TO PLANT COMMUNITIES AND THEIR SUCCESSIONAL STAGES

Jack Ward Thomas, USDA Forest Service,
Route 2, Box 2315, La Grande, Oregon

Rod Miller, USDA Forest Service,
Baker, Oregon

Chris Maser, U.S. Department of the Interior
Bureau of Land Management, La Grande, Oregon

Ralph Anderson, USDA Forest Service
Wallowa, Oregon

Bernie Carter, USDA Forest Service,
Prineville, Oregon

Abstract: Increasing demands for an accounting of environmental impacts caused by government actions has made necessary an appraisal of impacts on the entire vertebrate complex rather than on a few selected species. A system is described that relates species to forest plant communities and their successional stages. Information is presented at five levels of detail: (1) vertebrates are divided into "life forms" based on similar habitat requirements for feeding and reproduction; (2) individual species within life forms are examined based on habitat requirements for feeding and reproduction; (3) detailed biological data are presented for each species in terms of reproductive rate, season of occurrence, territory or home range, and orientation to special or unique habitat features; and (4) the three best literature citations on each species. Prediction of habitat condition can then be translated into effects on wildlife.

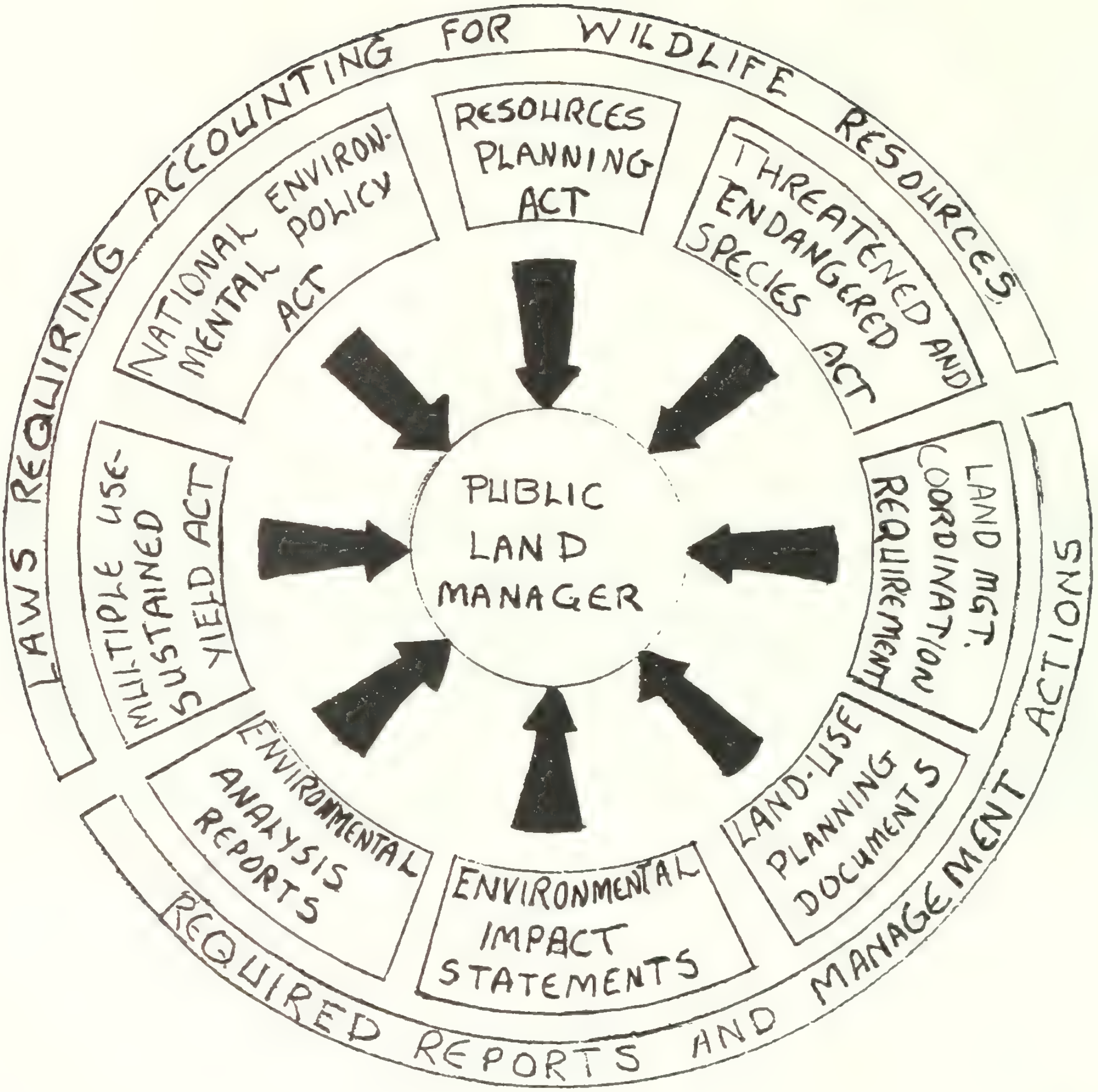
NEED FOR A COMPREHENSIVE SYSTEM

NEW DEMANDS IN PLANNING

Recent events, such as emerging environmental awareness and concern on the part of the American people, which have been reflected in laws, regulations, and court actions, have made the jobs of land managers more complex (Figure 1). These complex requirements include environmental impact statements and land use planning documents. Each requires the prediction of consequences of land management decisions on the wildlife within the area concerned.

BROADENED DEFINITION OF "WILDLIFE"

"Wildlife" has assumed a broader meaning in the past decade. Gone are the days when "wildlife" was defined, by most land managers, in terms of game species or was confined to a relatively few species of particular interest. The increasing recognition of ecological principles--everything is connected to everything else, and there is no such thing as a "free lunch" (Commoner 1971)--makes it mandatory that managers take a more holistic view of the system within which they work.



LAWS REQUIRING ACCOUNTING FOR WILDLIFE RESOURCES
RESOURCES PLANNING ACT
THREATENED AND ENDANGERED SPECIES ACT
LAND MGT. COORDINATION REQUIREMENT
LAND-USE PLANNING DOCUMENTS
ENVIRONMENTAL IMPACT STATEMENTS
ENVIRONMENTAL ANALYSIS REPORTS
MULTIPLE USE-SUSTAINED YIELD ACT
NATIONAL ENVIRONMENTAL POLICY ACT
PUBLIC LAND MANAGER
REQUIRED REPORTS AND MANAGEMENT ACTIONS

Figure 1. Planning requirements concerning wildlife values that have influence on public land managers.

REQUIREMENTS OF THE PLANNING SYSTEM

Our charge was to derive a system that would enable forest land managers and planners to predict consequences of environmental alterations (Figure 2). Three primary problems emerged: 379 terrestrial vertebrates occur in the Blue Mountains (26 amphibians and reptiles, 263 birds, and 90 mammals); data on each varied from voluminous to essentially none; and even if all information necessary for detailed management of each species was given to planners and decisionmakers, it would only "boggle the mind."

We had to accomplish the following:

(1) Display information available on animal response to habitat condition so that it could be considered in tandem with timber management and land use planning.

(2) Present the animal response data so as not to overwhelm the general planner with detail but at the same time, provide the wildlife specialist sufficient information to address problems or questions on individual species.

(3) Deal with habitat and its predicted conditions as the key planning component--recognizing that inventory of 379 terrestrial vertebrates on a continuing basis was prohibitively expensive if not impossible.

TIMBER MANAGEMENT AND WILDLIFE MANAGEMENT

We recognize that timber management is the dominant land management activity of the area and that any wildlife management of large scope will be the result, planned or unplanned, of such management--that is, timber management is wildlife habitat management (Figure 3). So, it was necessary to operate inside a conceptual framework common to foresters and wildlife biologists--indeed to all with a rudimentary ecological background.

THE PLANNING FRAMEWORK

PLANT COMMUNITY TYPES AND THEIR SUCCESSIONAL STAGES

The common framework selected was plant community types (timber types), their successional stages (Figure 4), and the arrangements of such stages or conditions in time and space (Figure 5). The reaction of wildlife species to such combinations was the vehicle for considering and predicting wildlife response to alterations in these habitats.

THE PLANT COMMUNITY TYPE AS SITE INDICATOR

The plant community type was accepted as the indicator of the variables that make up the site (Daubenmire 1976), and the wildlife was assumed to react primarily to the resulting structure of the plant community and its successional stages. Further, this animal reaction was considered in terms of orientation to the plant community and its stage or condition for feeding and reproduction. The forested plant communities and their successional stages have been discussed for the Blue Mountains by Franklin and Dyrness (1973).

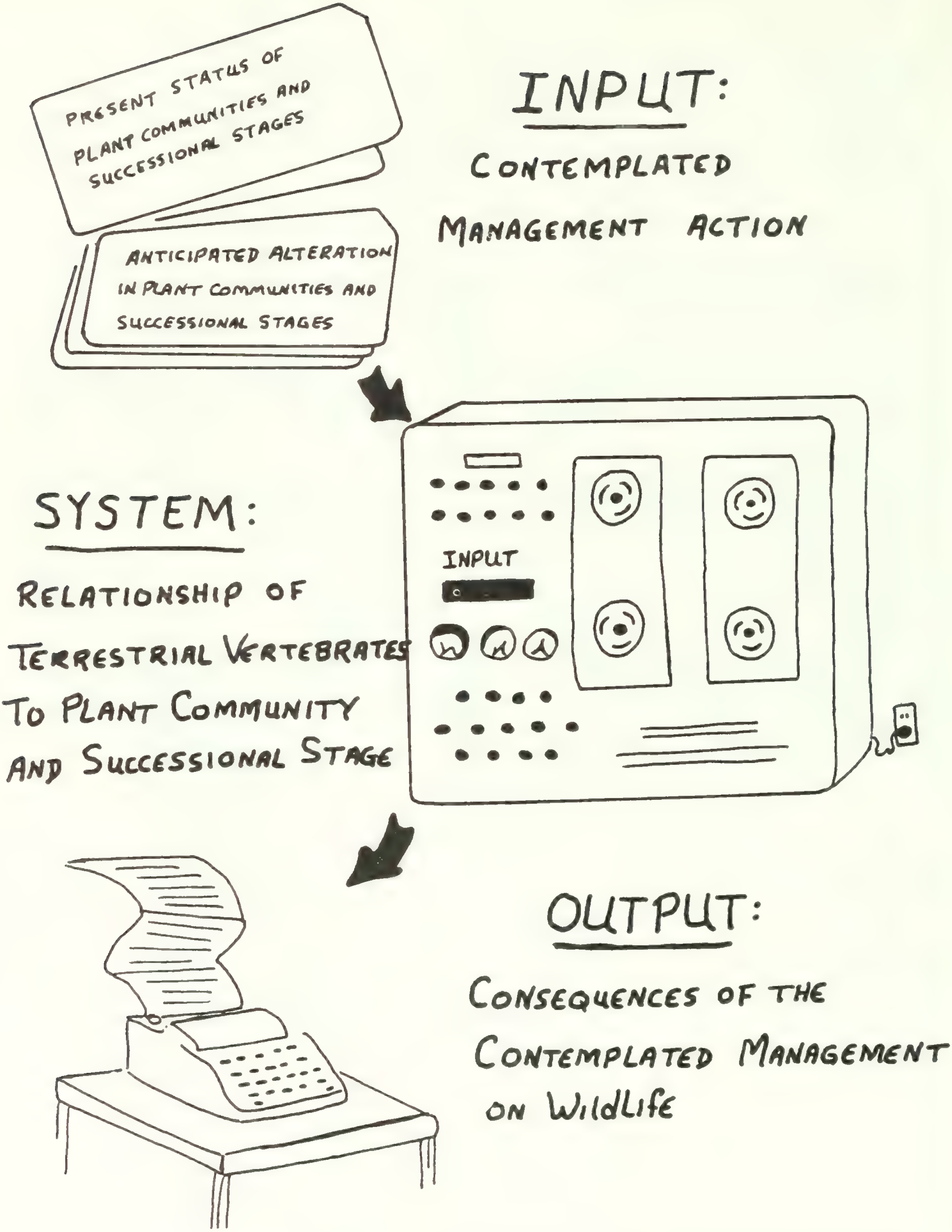

PRESENT STATUS OF PLANT COMMUNITIES AND SUCCESSIONAL STAGES
ANTICIPATED ALTERATION IN PLANT COMMUNITIES AND SUCCESSIONAL STAGES
INPUT:
CONTEMPLATED MANAGEMENT ACTION
SYSTEM:
RELATIONSHIP OF TERRESTRIAL VERTEBRATES TO PLANT COMMUNITY AND SUCCESSIONAL STAGE
INPUT
OUTPUT:
CONSEQUENCES OF THE CONTEMPLATED MANAGEMENT ON WILDLIFE

Figure 2. The analysis had to provide a method of predicting consequences of habit alterations on wildlife.

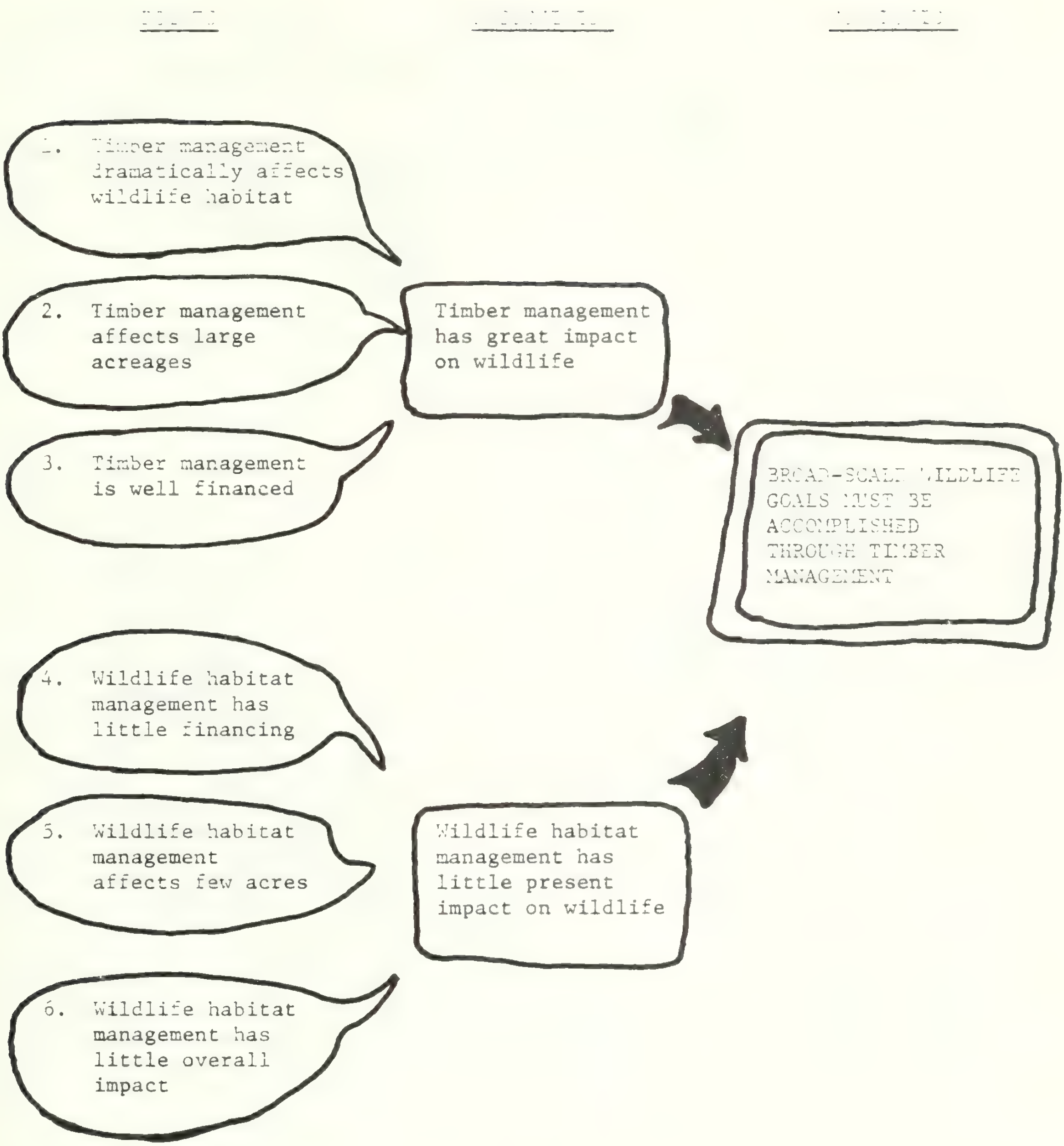
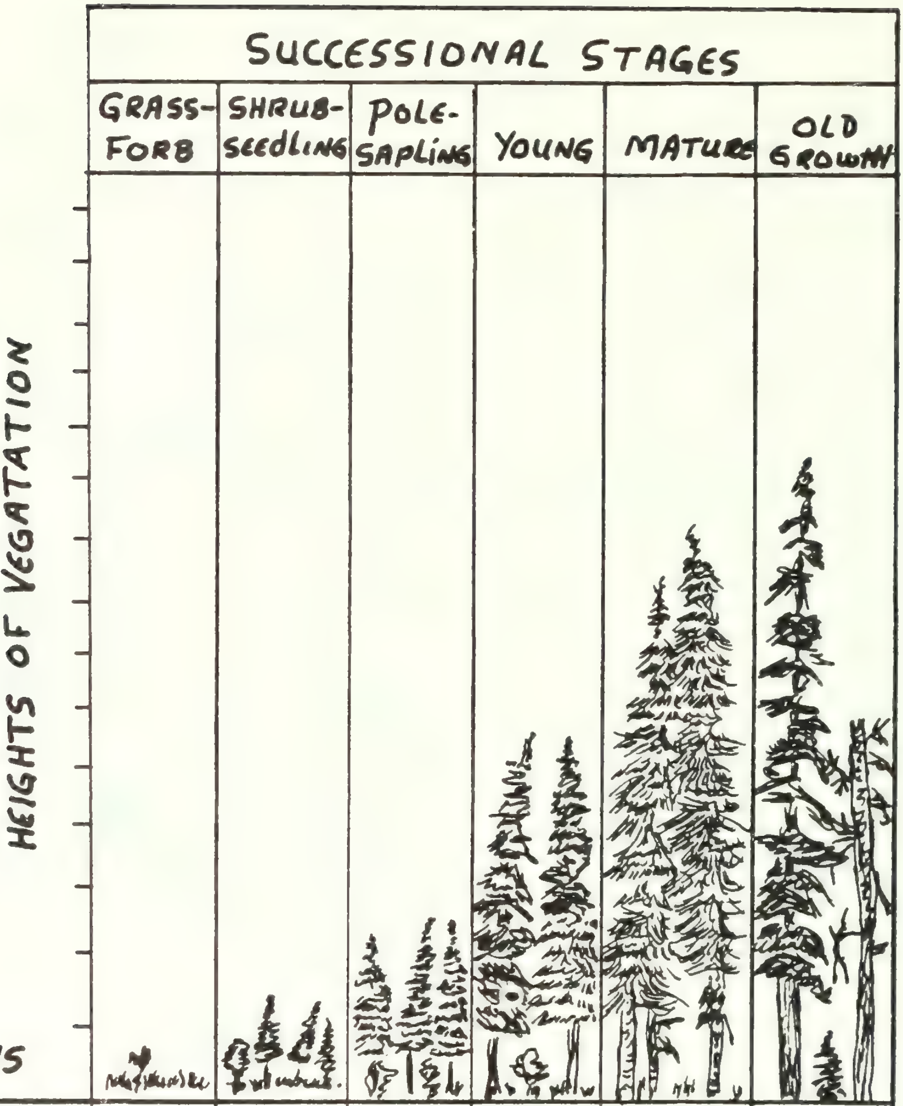

1. Timber management dramatically affects wildlife habitat
2. Timber management affects large acreages
3. Timber management is well financed
Timber management has great impact on wildlife
BROAD-SCALE WILDLIFE GOALS MUST BE ACCOMPLISHED THROUGH TIMBER MANAGEMENT
4. Wildlife habitat management has little financing
5. Wildlife habitat management affects few acres
Wildlife habitat management has little present impact on wildlife
6. Wildlife habitat management has little overall impact

Figure 3. Broad-scale wildlife habitat management will be the result, planned or unplanned, of timber management.



CONDITIONS	GRASS-FORB	SHRUB-SEEDLING	POLE-SAPLING	YOUNG	MATURE	OLD GROWTH
CANOPY CLOSURE	x	xx	xxxx	xxxxx	xxxx	xxx
FORAGE PRODUCTION	xxxxx	xxx	xx	x	xx	xxx
BROWSE PRODUCTION	x	xxxxx	xx	x	xx	xxx
CANOPY VOLUME		x	xx	xxx	xxxxx	xxxx
PLANT DIVERSITY	xx	xxxxx	xxx	x	xx	xxx
STRUCTURAL DIVERSITY	x	xxxx	xx	x	xx	xxxxx
ANIMAL DIVERSITY	xxx	xxxx	x	xx	xxxxx	xxxx
ETC.						

Figure 4. Generalized forest successional stages and relative environmental conditions.

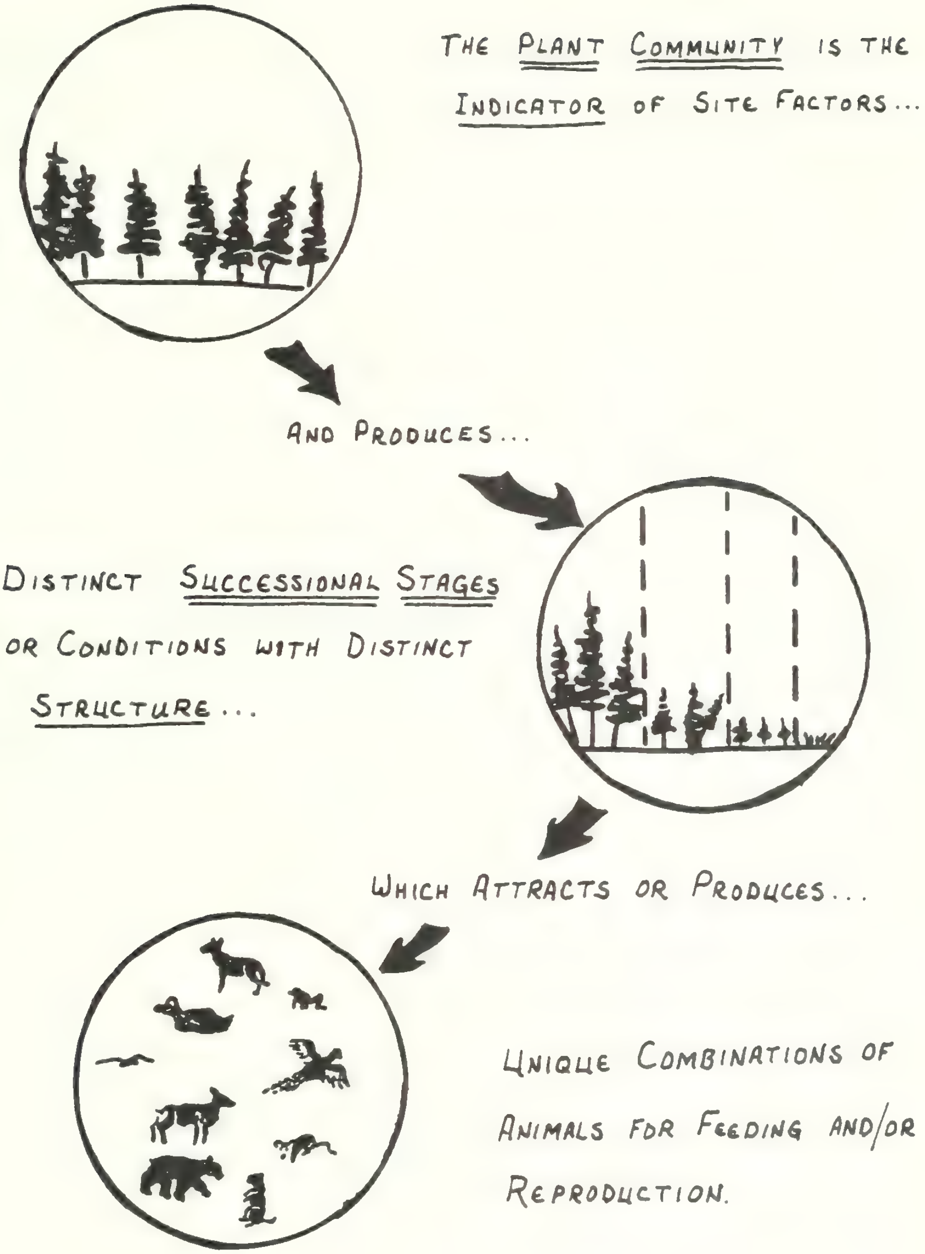

The Plant Community is the Indicator of Site Factors...
And Produces...
Distinct Successional Stages or Conditions with Distinct Structure...
Which Attracts or Produces...
Unique Combinations of Animals for Feeding and/or Reproduction.

Figure 5. The Wildlife-forestry planning framework.

LEVELS OF DETAIL

The wildlife-habitat association models were developed so that planners and land managers could extract information at four levels of detail depending on their requirements. These include:

(1) Relationship of animal life forms to plant communities and their successional stages or conditions for purposes of feeding and reproduction.

(2) Relationship of individual species, within life forms, to plant communities and their successional stages or conditions for purposes of feeding and reproduction.

(3) A measure of relative vulnerability of each species, within life forms, to habitat manipulation.

(4) Detailed information for each species in terms of a summary of available biological data.

(5) Key literature references for each species concerning habitat relationships.

Informational displays were constructed from the following sources: (1) literature, (2) interpretation and extrapolation of that literature, and (3) experience or opinions or both of the team of biologists. A principle of "best available information" was followed. Naturally, data on the most intensively studied species were more voluminous and detailed than on relatively obscure species. The system must be subject to periodic updating as the state of knowledge improves on individual species in relationship to their habitats, particularly within the specific area of concern.

TERRESTRIAL VERTEBRATE LIFE FORMS

DEFINITION

The sheer numbers of wildlife species present in the Blue Mountains make it difficult for the land manager to account for them all in the land use planning process. We have reduced this volume from 379 species to 16 "life forms" (Table 1). This life form concept was adapted from Haapanen's (1965) division of birds of the Finnish forest into groups based on specific combinations of habitat requirements for reproduction and for feeding.

LEVELS OF DETAIL

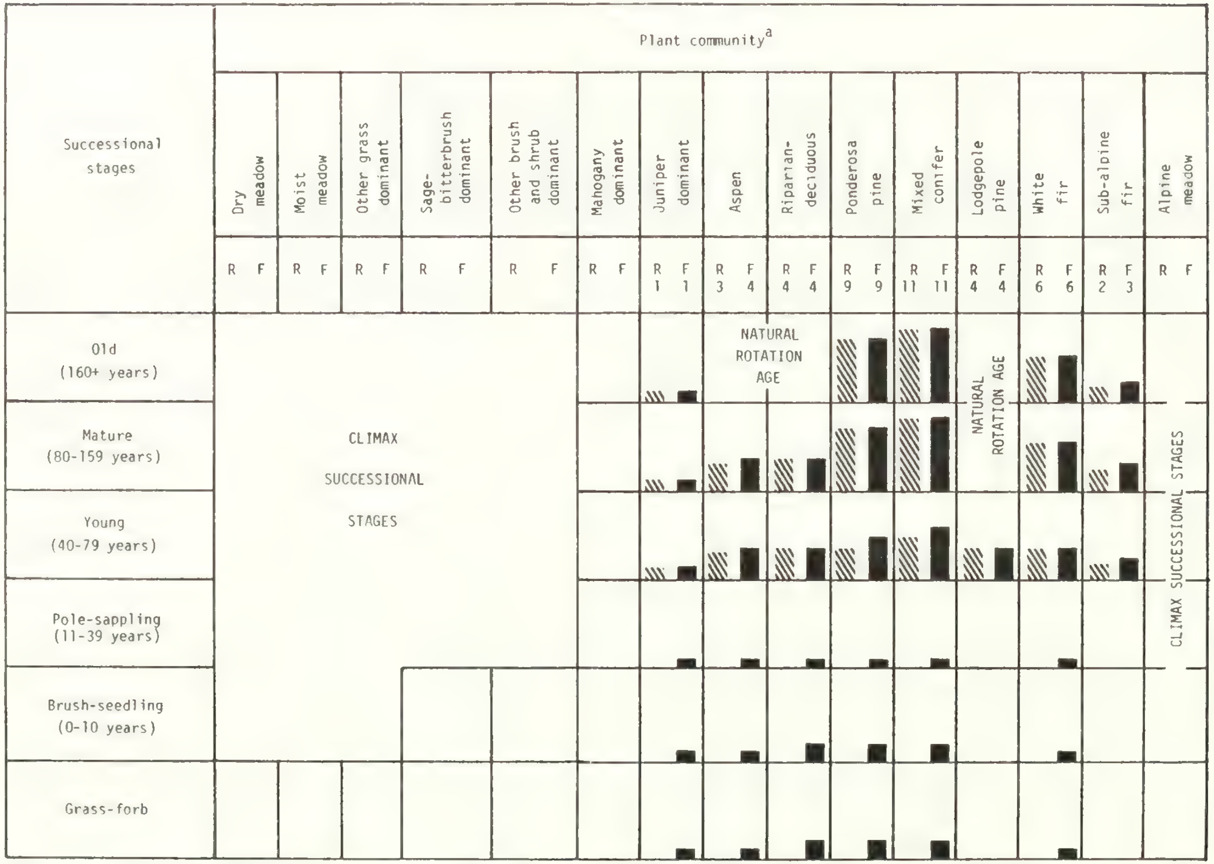
RELATIONSHIP OF ANIMAL LIFE FORMS TO PLANT COMMUNITY TYPES AND SUCCESSIONAL STAGES

The relationships of vertebrate life forms to plant community types and successional stages were examined by means of a visual display. An example, life form 13 (reproduction--excavates its own hole in a tree; feeding--on ground, in bushes, trees, or air), is shown in Table 2.

Table 1. Description of Vertebrate Life Forms Occurring in the Blue Mountains, Oregon

Life form number	Reproduces	Feeds
1	In water	In water
2	In water	On ground, in bushes and/or trees
3	On ground around water	In water, on ground, in bushes and trees
4	In cliffs, caves, rims, and/or talus	On ground or in air
5	On ground without specific water, cliff, rim, or talus association	On ground
6	On ground	In bushes, trees, or air
7	In bushes	On ground, in water or air
8	In bushes	In bushes, trees, or air
9	Primarily in deciduous trees	In bushes, trees, or air
10	Primarily in conifers	In bushes, trees, or air
11	In trees	On ground, in bushes, trees, or air
12	On very thick branches	On ground or in water
13	Excavates own hole in a tree	On ground, in bushes, trees or air
14	In a hole made by another species or naturally occurring	On ground, in water, or air
15	Underground burrow	On or under ground
16	Underground burrow	In water or air

Table 2. Relative Degree of Use by the Life Form of Indicated Plant Communities and Successional Stages for Life Form 13. Excavates Own Hole, Feeds on Ground, in Bushes, Trees or Air (cross-hatching indicates reproduction orientation, darkened bar indicates feeding orientation.)



Successional stages	Plant community[a] Dry meadow R F	Moist meadow R F	Other grass dominant R F	Sage-bitterbrush dominant R F	Other brush and shrub dominant R F	Mahogany dominant R F	Juniper dominant R 1 F 1	Aspen R 3 F 4	Riparian-deciduous R 4 F 4	Ponderosa pine R 9 F 9	Mixed conifer R 11 F 11	Lodgepole pine R 4 F 4	White fir R 6 F 6	Sub-alpine fir R 2 F 3	Alpine meadow R F
Old (160+ years)	CLIMAX SUCCESSIONAL STAGES						▨ ■	NATURAL ROTATION AGE		▨ ■	▨ ■	NATURAL ROTATION AGE	▨ ■	▨ ■	
Mature (80-159 years)							▨ ■	▨ ■	▨ ■	▨ ■	▨ ■		▨ ■	▨ ■	CLIMAX SUCCESSIONAL STAGES
Young (40-79 years)							▨ ■	▨ ■	▨ ■	▨ ■	▨ ■	▨ ■	▨ ■	▨ ■	
Pole-sappling (11-39 years)							■	■	■	■	■		■		
Brush-seedling (0-10 years)							■	■	■	■	■		■		
Grass-forb							■	■	■	■	■		■		

[a] Number of species using these plant communities are listed under reproduction (R) and feeding (F).

NOTE: Only species known to reproduce in Area 3 are shown on the various life form tables. Total number of species in life form 13.

A low degree of use of a certain successional stage of a plant community indicates low use of that stage by the life form as a whole. A particular species within the life form may be highly dependent on that one stage. For more detail see Figures 2 and 3.

USE IN PLANNING

What information useful to the land manager or planner can be derived from such displays? Using Table 2 as an example, he can discern that: (1) vertebrate life form 13 is highly associated with forested communities, (2) some forested communities--ponderosa pine and mixed conifer--are disproportionately important, and (3) the older forest successional stages are critical. In other words, presence or absence of reproductive and feeding orientation to plant community types and their successional stages can be determined for the life form as a whole.

ACCOUNTING FOR HABITAT ALTERATIONS

Further, the displays can be used to predict the response of animal life to alterations of the plant community. Such alterations can be the result of a "natural" phenomenon (such as fire, insect infestation, or blow down) or management action (such as seeding, planting, herbicide treatment, thinning, or fertilization).

Any of these actions can be conceived, albeit roughly, as either advancing or retarding succession (Thomas et al. 1975); for example, planting trees advances the normal state of succession, thinning and fertilization makes stands appear older, and wildfire sets the succession back. We assumed that the wildlife component of the community is largely a product of the vegetative structure of that community and not of the age of the vegetation that makes up that structure. Some anticipated responses to vegetative manipulation practices are shown in Table 3.

ASSOCIATIONS OF VERTEBRATE SPECIES WITH PLANT COMMUNITY TYPES AND SUCCESSIONAL STAGES

Vertebrate life form responses to plant community and successional stage or condition are generalized. There is variation in responses based on the specific habitat requirements of the species that make up the life form. The primary orientation of the individual species to plant communities is indicated in life form 13 (Table 4). Information dealing with species orientation to successional stages or conditions within a life form is illustrated in Table 5.

The key to use for feeding and reproduction by community is derived from Table 5. This key carries over to the successional stage data shown in Table 6. If a species shows orientation to several plant communities, for feeding or reproduction or both, that information would carry over to the tables on orientation to successional stage. For example, community data for the pygmy nuthatch (life form 13, Table 4) shows orientation to the aspen community for feeding only. When reference is made to successional stage tables (Table 5) it is necessary to delete reproductive orientation from consideration. In the case of the relationship between the pygmy nuthatch and the aspen type the "X's" showing reproductive orientation are ignored in the successional stage tables.

Information other than the particular species requirements may be derived from Tables 4 and 5. The totals of the number of species oriented to each plant community for feeding and reproduction were used to produce Table 3 that demonstrates the orientation of the life form. Likewise, the totals of

Table 3. Anticipated Changes in Forest Community Structure Due to Management Action

Management action	Successional stage of condition[a]					
	Grass-forb	Shrub-seedling	Pole-sapling	Young	Mature	Old growth
Brush control						
Herbicides	→	→	→	←	←	←
Mechanical control	←	←	-	←	←	←
Controlled burn						
Cold burn	←	←	→	→	←	←
Hot burn	←	←	←	←	←	←
Fertilization	-	→	→	→	→	-
Grazing						
Cattle and sheep	→	→	-	-	-	-
Goats	←	←	-	←	←	←
Planting						
Trees	→	→	-	→	→	-
Shrubs	→	-				
Grasses-forbs	→	←	-	→	→	-
Regeneration cut						
Clear cut				←	←	←
Shelterwood				→	←	←
Seed tree				←	←	←
Salvage			←	←	←	←
Thinning (including single tree selection)		→	→	→	→	-

[a] → advances succession; ← retards succession; - no effect on succession.

Table 4. Species Orientation by Plant Community for Life Form 13 Excavates own Hole, Feeds on Ground, in Bushes, Trees, or Air, X = Reporduction; 0 = Feeding

Species		Juniper dominant[a]	Aspen[b]	Riparian deciduous	Ponderosa pine[c]	Mixed conifer	Lodgepole pine[c]	White fir[e]	Subalpine fir[f]	Number of plant communities in which species occur	
										Reproduction	Feeding
Common flicker *Colaptes auratus*		X 0	X 0	X 0	X 0	X 0		X 0		6	6
Pileated woodpecker *Dryocopus pileatus*					X 0	X 0		X 0		3	3
Lewis' woodpecker *Asyndesmus lewis*				X 0	X 0	X 0				3	3
Yellow-bellied sapsucker *Sphyreapicus varius*			X 0	X 0	X 0	X 0				4	4
Williamson's sapsucker *Sphyrapicus thyroideus*					X 0	X 0		X 0		3	3
Hairy woodpecker *Dendrocopos villosus*					X 0	X 0	X 0	X 0	X 0	5	5
Downy woodpecker *Dendrocopos pubescens*			X 0	X 0						2	2
White-headed woodpecker *Dendrocopos albolarvatus*					X 0	X 0				2	2
Black-backed three-toed woodpecker *Picoides arcticus*						X 0	X 0	X 0	0	3	4
Northern three-toed woodpecker *Picoides tridactylus*							X 0		X 0	2	2
White-breasted nuthatch *Sitta carolinensis*					X 0	X 0				2	2
Red-breasted nuthatch *Sitta canadensis*						X 0	X 0	X 0		3	3
Pygmy nuthatch *Sitta pygmaea*			0		X 0	X 0				2	3
Number of species using plant community	Reproduction	1	3	4	9	11	4	6	2		
	Feeding	1	4	4	9	11	4	6	3		

---

[a] *Juniperus occidentalis*

[b] *Populus tremuloides*

[c] *Pinus ponderosa*
Pseudotsuga menziesii
Albies grandis
Pinus cortorta

[d] *Pinus Contorta*

[e] *Abies grandis*

[f] *Abies lasiocarpa*

Table 5. Species Orientation by Successional Stages for Life Form 13 (Excavates Own Hole, Feeds on Ground, in Bushes, Trees, or Air, X = Reproduction; 0 = Feeding

	Grass-forb	Brush-seedling (0-10 years)	Pole-sapling (11-39 years)	Young (40-79 years)	Mature (80-159 years)	Old (160+ years)	Number of successional stages in which species occur: Reproduction	Number of successional stages in which species occur: Feeding
Common flicker	0	0	0	X 0	X 0	X 0	3	6
Pileated woodpecker					X 0	X 0	2	2
Lewis' woodpecker	0	0		X 0	X 0	X 0	3	5
Yellow-bellied sapsucker				X 0	X 0	X 0	3	3
Williamson's sapsucker					X 0	X 0	2	2
Hairy woodpecker				X 0	X 0	X 0	3	3
Downy woodpecker				X 0	X 0	X 0	3	3
White-headed woodpecker					X 0	X 0	2	2
Black-backed three-toed woodpecker				X 0	X 0	X 0	3	3
Northern three-toed woodpecker				X 0	X 0	X 0	3	3
White-breasted nuthatch					X 0	X 0	2	2
Red-breasted nuthatch				X 0	X 0	X 0	3	3
Pygmy nuthatch				0	X 0	X 0	2	3
Number of species using successional stage: Reproduction				8	13	13		
Number of species using successional stage: Feeding	2	2	1	9	13	13		

the species showing orientation to successional stages by plant community were used to construct Table 2.

The relationship of wildlife numbers to each forested community is shown in Figure 6. Obviously, some communities produce considerably more species of wildlife than others. Ponderosa pine and mixed conifers, the communities most heavily impacted by timber management in the Blue Mountains, are the most productive in terms of wildlife species.

Using such data, the land manager or planner can determine the individual species associated with each plant community. Then, using the same data, the land manager or planner can predict the response of the individual species to alterations in successional stage or condition.

For example, a series of timber sales are planned in an extensive 80-year-old lodgepole pine area. The area is a dense canopied stand with little understory. What species in vertebrate life form 13 are potentially affected? Table 4 shows that of 13 species in that life form, four (hairy woodpecker, black-backed three-toed woodpecker, northern three-toed woodpecker, and the red-breasted nuthatch) have a strong association with lodgepole pine for both feeding and reproduction.

Then, what effect would clearcutting of, say, 35 percent of the area have on these species? Such action would put those areas into the grass-forb successional stage. Table 5 shows that the four species involved are oriented to the mature successional stage for both feeding and reproduction. None show orientation to the grass-forb stage. It can be concluded that clearcutting will reduce habitat for those species by approximately 35 percent for a period of at least 40-50 years--that being the time required for the stands to regenerate and reach a successional stage or condition suitable for reoccupancy.

Similar information could be developed for all lodgepole stands from appropriate tables for all life forms (i.e., Tables 4 and 5).

The generalized relationship of the wildlife of the Blue Mountains to successional stages of the forested communities is illustrated in Figure 7. This relationship shows why there has been concern expressed about the effects of intensive timber management on wildlife diversity and on the welfare of species narrowly adapted to certain successional stages or conditions--particularly grass-forb, shrub-seedling, and old growth (Wight 1974, Meslow and Wight 1975, Thomas et al. 1975).

VULNERABILITY INDEX

DEVELOPMENT OF THE INDEX

Each species exhibits a different degree of adaptability in terms of the number of plant communities and successional stages or conditions that it can use successfully for feeding or reproduction or both. Vulnerability of each species to habitat change is directly related to that adaptability. Species that are most adaptable are the least vulnerable to habitat manipulation. Conversely, those that are least adaptable are the most vulnerable.

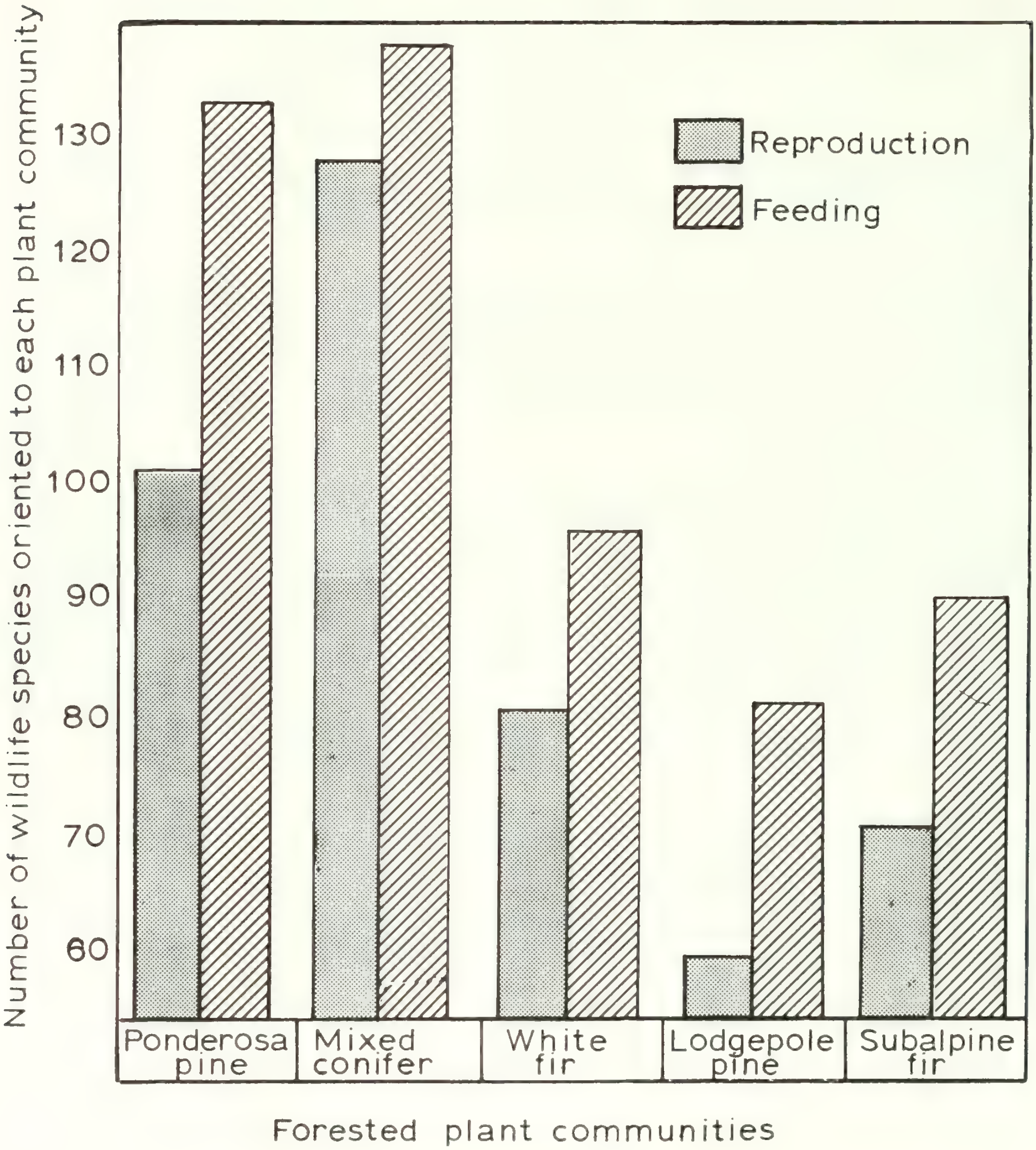


Figure 6. Wildlife species oriented to forested plant communities.

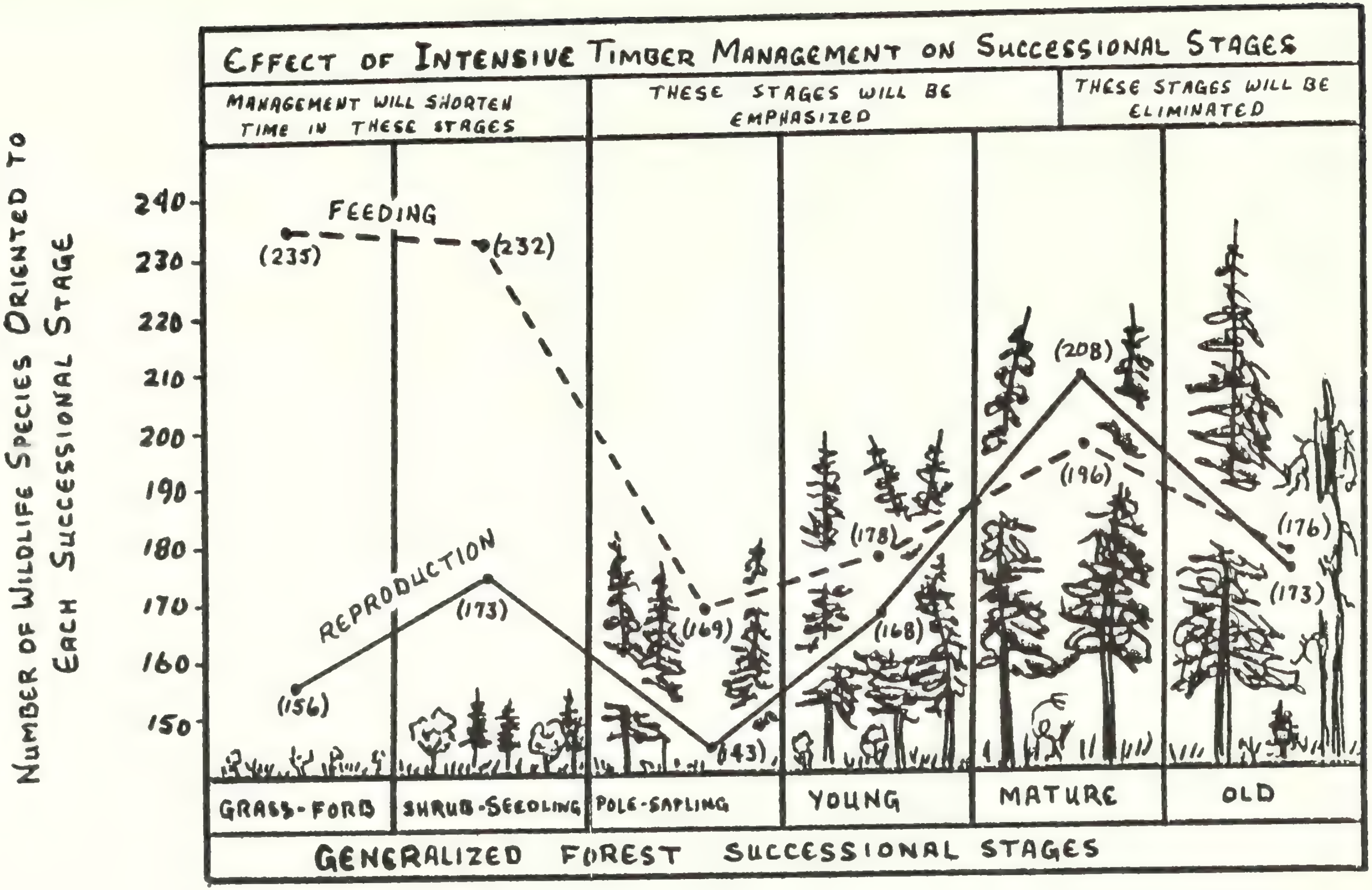


Figure 7. Number of wildlife species oriented to generalized forest successional stages and the potential effect of intensive timber management on those stages.

Data such as that displayed in Tables 4 and 5 were used to develop an index of vulnerability (V Index). The data used in developing this index were the total number of plant communities and the total number of successional stages to which the species shows primary orientation for feeding and reproduction. Habitat for reproduction was given double weight (by dividing by a factor of 2) because it was considered more important for species survival; the lower the score the lower the species' adaptability and the higher its vulnerability. The V Index was derived as follows:

$$\text{V Index} = \left(\frac{\begin{array}{l}\text{No. of}\\\text{communi-}\\\text{ties used}\\\text{for repro-}\\\text{duction}\end{array} + \begin{array}{l}\text{No. of}\\\text{succes-}\\\text{sional}\\\text{stages used}\\\text{for repro-}\\\text{duction}\end{array}}{2} \right) + \left(\begin{array}{l}\text{No. of}\\\text{communi-}\\\text{ties used}\\\text{for repro-}\\\text{duction}\end{array} + \begin{array}{l}\text{No. of}\\\text{succes-}\\\text{sional}\\\text{stages used}\\\text{for repro-}\\\text{duction}\end{array} \right)$$

An example of V scores and their derivation are shown in Table 6.

IDENTIFICATION OF SPECIES OF PARTICULAR INTEREST

Note the bars in Table 6 that graphically compare V scores. Species of special interest in terms of their potentially rare or threatened status, on either a local, state, or national basis are identified by cross-hatching. Those species not identified as potentially rare or threatened are indicated by solid bars. These species were so identified by Arbib (1975), the U.S. Department of the Interior (1973), and Dyrness et al. (1975). The species in question and the authority that so identified them as rare or threatened are shown in Table 7.

A comparison of V scores quickly identifies the species that are least adaptable and most vulnerable; they may require particular management attention to their needs to insure their continued existence in viable numbers. These scores reflect the V scores of the species only in the Blue Mountains. It is quite possible that a nationally common bird may show a low V score for the Blue Mountains because suitable habitats are limited.

DETAILED DATA SUMMARY BY SPECIES

The final level of detail is a summary of key information on each species. Some of that information was derived from tables already presented and some from other sources. These displays serve two purposes: (1) to summarize information on an individual species as opposed to a life form basis, and (2) to present key data needed for accounting of species welfare in planning and management activities. Table 8 gives an example of such data for selected species.

KEY LITERATURE BY SPECIES

If the information displayed thus far is not sufficient for the needs of the planner or land manager, three or more of the best references for each species that were reviewed in preparation of already mentioned tables are

Table 6. Vulnerability (V) Ratings of Species for Life Form 13 (Excavates Own Hole, Feeds on Ground, in Bushes, Trees, or Air)

	Reproductive Orientation[a]				Feeding Orientation				V Rating[c]		
Species	No of successional stages used	No. of plant communities used	1 + 2	3/2	No. of successional stages used	No. of plant communities used	5 + 6	V Score[b] 4 + 7	High V	Moderate V	Low V
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	1-6	7-12	13-18
Common flicker	3	6	9	4.5	6	6	12	16.5	■	■	■
Pileated woodpecker	2	3	5	2.5	2	3	5	7.5	■	■	
Lewis' woodpecker	3	3	6	3.0	5	3	8	11.0	▨	▨	
Yellow-bellied sapsucker	3	4	7	3.5	3	4	7	10.5	■	■	
Williamson's sapsucker	2	3	5	2.5	2	3	5	7.5	■	■	
Hairy woodpecker	3	5	8	4.0	3	5	8	12.0	▨	▨	
Downy woodpecker	3	2	5	2.5	3	2	5	7.5	■	■	
White-headed woodpecker	2	2	4	2.0	2	2	4	6.0	■		
Black-backed three-toed woodpecker	3	3	6	3.0	3	4	7	10.0	■	■	
Northern three-toed woodpecker	3	2	5	2.5	3	2	5	7.5	▨	▨	
White-breasted nuthatch	2	2	4	2.0	2	2	4	6.0	■		
Red-breasted nuthatch	3	3	6	3.0	3	3	6	9.0	■	■	
Pygmy nuthatch	2	2	4	2.0	2	3	5	7.0	■	■	

[a] Reproductive orientation is weighted doubly for the feeding orientation; this is done by dividing the sum of columns 1 and 2 (= column 3) by 2. The results are shown in column 4.

[b] The vulnerability score is derived by adding columns 4 and 7. The lower the score, the lower the species' adaptability and the higher its vulnerability.

[c] ▨ species of special interest listed by U.S. Department of the Interior (1973), Arbib (1975), and Dyrness et al. (1975). Length of the bar indicates the V rating.

■ species not designated as of special interest. Length of the bar indicates the V rating.

Table 7. Examples of Species of Special Interest Due to Potentially Rare of Threatened Status in the Blue Mountains[a]

Species No.	Life Form Number	Species	Federal Register[b]	Oregon Department of Fish and Wildlife[c]	U.S. Dep. Interior, Fish and Wildlife Service[d]	U.S. Dep. Agriculture, Forest Service[e]	Oregon State University[f]	Audubon Society - 1976[g]	U.S. Forest Service - Region 6[h]	Idaho Game Department[i]
58	12	Osprey (*Pandion haliaetus*)			SU	SI	R	X	U	SU
59	4	Prairie falcon (*Falco mexicanus*)			T	SI	R	X	R	T
60	4	Peregrine falcon (*F. peregrinus*)	E	E	T	SI	E		E	T
61	11	Merlin (*F. columbarius*)				SI	E	X		
62	14	American kestrel (*F. sparverius*)				SI				

[a] Codes: X - occurs on the list, E - endangered, T - threatened, R - rare, SU - status undetermined, SI - species of special interest, P - peripheral, U - unique, * - may feed in the Blue Mountains, not known to reproduce there. Included here but not on individual life form lists.

[b] Federal Register (1973).

[c] Shay (1973).

[d] U.S. Department of the Interior (1973).

[e] Dyrness et al. (1975).

[f] Marshall (1969).

[g] Arbib (1975).

[h] Forsman, J.S. 1971. Endangered species list, USDA Forest Service R-6, typed report. 5 p. Region 6, Portland, Oregon.

[i] Mohler (1974).

Table 8 Detailed Habitat Data by Species

LEGEND
Reproduction orientation ■ primary (40 100%)
▧ secondary or casual (0-40%)
Feeding orientation ▥ primary (40-100%)
▨ secondary (0-40%)

H = high
M = medium
L = low

Species number	Life form number	Species	Versatility rating	Function	Activity/seasonal occurrence												Potential reproductive capacity/year	Home range and/or territory size (in acres)	Minimum habitat required for pair or population
					January	February	March	April	May	June	July	August	September	October	November	December			
134	13	Common flicker	H	reprod.					■	■									
				feeding	▥	▥	▥	▥	▥	▥	▥	▥	▥	▥	▥	▥			
135	13	Pileated woodpecker	M	reprod				■	■	■									
				feeding	▥	▥	▥	▥	▥	▥	▥	▥	▥	▥	▥	▥			
136	13	Lewis' woodpecker	M	reprod					■	■									
				feeding			▥	▥	▥	▥	▥	▥	▥						
137	13	Yellow-bellied sapsucker	M	reprod				■	■	■									
				feeding				▥	▥	▥	▥	▥	▥						
138	13	Williamson's sapsucker	M	reprod					■	■									
				feeding			▥	▥	▥	▥	▥	▥	▥	▥	▥				
139	13	Hairy woodpecker	H	reprod				■	■	■									
				feeding	▥	▥	▥	▥	▥	▥	▥	▥	▥	▥	▥	▥			
140	13	Downy woodpecker	M	reprod			■	■	■										
				feeding	▥	▥	▥	▥	▥	▥	▥	▥	▥	▥	▥	▥			

Species number	Species	Function	Plant community groups														Key habitat component												
																	Riparian					Ecotones							
			Dry meadow	Moist meadow	Other grass dominant	Sage-bitterbrush dominant	Other brush and shrub dominant	Mountain mahogany dominant	Juniper dominant	Aspen	Ponderosa pine	Mixed conifer	True fir	Lodgepole pine	Sub-alpine fir	Alpine meadow	River, creek stream	Lake, reservoir	Marsh, bog, swamp	Standing or slow moving water	Fast, running water	Brush-grass	Forest-brush	Forest-grass	Cliffs, rims	Talus	Caves, burrows	Snags	Down material
134	Common flicker	reprod.								■	■	■	▧	▧	▧		■	■					■	■				■	
		feeding	▨	▨	▨	▨	▨	▨	▨	▥	▥	▥	▨	▨	▨		▥	▥				▥	▥	▥				▥	▥
135	Pileated woodpecker	reprod								▧	■	■	■		▧		▧						■	■				■	
		feeding									▥	▥	▥	▥	▥								▥	▥				▥	▥
136	Lewis' woodpecker	reprod								▧	■	■					■	■					■	■				■	
		feeding		▥	▥		▥		▨	▨	▥	▥	▥		▨	▨	▥	▥					▥	▥				▥	
137	Yellow-bellied sapsucker	reprod								■	■	■					■	■					■	■				■	■
		feeding								▥	▥	▥	▥	▨	▨		▥	▥					▥	▥				▥	▨
138	Williamson's sapsucker	reprod								▧	■	■	■	■	■		▧	▧					■	■				■	
		feeding								▨	▥	▥	▨	▨	▥		▥	▥					▥	▥				▨	▥
139	Hairy woodpecker	reprod								▧	■	■	■	■	■		▧	▧					▧	▧				■	
		feeding								▨	▥	▥	▥	▥	▥		▨	▨					▨	▨				▥	▥
140	Downy woodpecker	reprod								■							■	■					■	■				■	
		feeding								▥	▨	▨					▥	▥					▥	▥				▥	

listed. If the user still does not find sufficient information, reference to the literature cited sections of these referenced works may provide useful leads to the information needed.

SUMMARY

Data such as that presented in this paper is nothing more than a data base from which the planners or land manager may draw information. The information is organized so that it can be extracted at the level of detail necessary for the job at hand. The information has been tested through its use in preparation of land use plans, environmental impact statements, and environmental analysis reports. It has enabled the users to produce better, more comprehensive, and more accurate results in a shorter period of time.

A last caution is in order. The information system presented here is best suited for use in broad-scale, land-use planning. The smaller the area planned and the greater the detail of the plan the less the probability that these data can be used to predict results; general predictive ability should still hold but variability increases as area size diminishes.

The point is that this information base is not intended to replace the trained, experienced wildlife biologist. In the hands of such a person the system can be useful. Conversely, if applied without interpretation, qualification, and sensitivity to individual conditions, the results will be less accurate.

LITERATURE CITED

Arbib, R. 1975. The blue list for 1976. Am. Birds 29(6):1067-1072.

Commoner, B. 1971. The closing circle. Alfred A. Knopf, New York. 326 pp.

Daubenmire, R. 1976. The use of vegetation in assessing the productivity of forest lands. Bot. Rev. 42(2):115-143.

Dyrness, C.T., J.F. Franklin, C. Maser, S.A. Cook, D. Hall, and G. Faxon. 1975. Research Natural Area Needs in the Pacific Northwest. USDA For. Serv. Gen. Tech. Rep. PNW-38, Pacific Northwest For. and Range Exp. Stn., Portland, Oregon. 231 pp.

Federal Register. 1973. United States list of endangered native fish and wildlife. Fed. Regist. 38(36), Monday 4 June.

Forsman, J.S. 1971. Endangered species list. USDA For. Serv. R-6, typed report. 5 p. Region 6, Portland, Oregon.

Franklin, J.F., and C.T. Dyrness. 1973. Natural Vegetation of Oregon and Washington. USDA For. Serv. Gen. Tech. Rep. PNW-8, Pacific Northwest For. and Range Exp. Stn., Portland, Oregon. 417 pp.

Haapanen, A. 1965. Bird fauna of the Finnish forests in relation to forest succession, I. Annu. Zool. Fenn. 2:153-196.

Marshall, D.B. 1969. Endangered Plants and Animals of Oregon. III. Birds. Oregon State Univ. Spec. Rep. 278, Corvallis. 23pp.

Meslow, E.C., and H.M. Wight. 1975. Avifauna and succession in Douglas-fir forests of the Pacific Northwest, pp. 266-271. In D.R. Smith (ed.) Symposium on Management of Forest and Range Habitats for Nongame Birds. USDA For. Serv. Gen. Tech. Rep. WO-1. Washington, D.C.

Mohler, L.L. 1974. 1974. Threatened wildlife of Idaho. Idaho Wildl. Rev. 26(5):3-5.

Shay, R. 1973. Oregon's Rare or Endangered Wildlife. Oreg. State Game Comm. Bull., Portland, Oregon. pp 3-8.

Thomas, J.W., G.L. Crouch, R.S. Bumstead, and L.D. Bryant. 1975. Silvicultural options and habitat values in coniferous forests, pp. 272-287. In D.R. Smith, (ed.) Symposium on Management of Forest and Range Habitats for Nongame Birds. USDA For. Serv. Gen. Tech. Rep. WO-1. Washington, D.C.

U.S. Department Interior. 1973. Threatened wildlife of the United States. Bur. Sport Fish. Wildl. Res. Bull. 114, Washington, D.C. 289 pp.

Wight, H.M. 1974. Non-game wildlife and forest management, pp. 27-38. In Wildlife and Forest Management in the Pacific Northwest. Edited by H.C. Black, Sch. For., Oregon State Univ., Corvallis.

ASSESSMENT OF HABITAT CONDITION BY MEASUREMENT OF BIOCHEMICAL AND ENDOCRINE INDICATORS OF THE NUTRITIONAL, REPRODUCTIVE, AND DISEASE STATUS OF FREE-RANGING ANIMAL POPULATIONS

U. S. Seal
Departments of Biochemistry and Wildlife,
University of Minnesota
St. Paul, Minnesota 55108

Abstract: Blood samples were collected during the course of field studies from six populations of white-tailed deer, two populations of red fox, one population of timber wolf, and three pronghorn antelope populations. Controlled experimental studies were conducted on captive populations of the white-tailed deer. Hematology, chemistries, and hormones were assayed as indicators of reproductive, nutritional, and disease status. The data were analyzed for effects of age, sex, season, location, and nutrition where known. Correlations with estimates of habitat quality were made where appropriate. The results from the studies of captive white-tailed deer indicated that a wide range of assays might serve as indicators of protein and energy intake in this species. It was also possible to differentiate between the wild populations and to relate some of these differences to probable differences in habitat. These experimental studies indicate that serum urea nitrogen is the most useful indicator of protein intake, whereas serum nonesterified fatty acids and triiodothyronine are useful indicators of differences in energy intake. Acute phase reactants, indicative of the presence of disease, were not affected by differences in protein and energy intake. Comparisons of the three pronghorn antelope populations revealed differences in serum urea nitrogen which were correlated with differences in the protein content of the plants utilized by these populations. The results of these several studies indicate that blood analyses may provide a useful tool for habitat assessment.

INTRODUCTION

The analysis of the status of wildlife populations by wildlife biologists and wildlife managers has traditionally included evaluations of habitat condition as well as the demographic characteristics of resident populations (Watson 1970, Perry and Rowlands 1973, Wetzel et al., 1975). The problem of predicting from one year to the next the composition, size, and density of these wildlife populations, or quantitatively defining carrying capacity from evaluations of habitat condition, has been persistently difficult (Watson 1970, Perry and Rowlands 1973, Van Valen 1973). Judgments are further complicated by the fact that most species are capable of utilizing a diversity of food resources and are capable of metabolic adjustments in the face of changing or limited food resources (Klein 1970). Collection of demographic data including changes in natality and mortality are frequently difficult and these changes in population demographic characteristics may be spread over several years of changes in habitat character (Perry and Rowlands 1973). Therefore, the possibility of making inferences concerning the proximate condition of habitat using data collected from individual animals of a population is especially appealing.

Survival and reproduction in a changing environment (Figure 1) require flexibility of response on the part of organisms (Van Valen 1976, Slobodkin and Rapoport 1974, Stearns 1976). Environmental perturbations may vary with respect to frequency, intensity, and periodicity. The scope of response of an animal may vary from a simple behavioral maneuver to minimize the effects of a short-term perturbation, to acclimitization in response to a persistent change in the environment, to death with failure to achieve an adequate response. Populations may respond with changes in death rates, selective changes in mortality and natality, and ultimately genetic changes, i.e., evolutionary change (Slobodkin and Rapoport 1974). The time frame or duration of the perturbation relative to the individual animal's capability of adaptive response will determine the extent to which adaptations of metabolic pathways occur. Thus, a behavioral response may occur and minimize or eliminate the effect of the environmental event. However, if this response is inadequate then short-term physiological changes may occur involving flow of small-molecular-weight substrates and metabolites by regulatory alterations at allosteric sites of key enzymes. These are commonly mediated by hormones. The next stage would involve changes in concentration of macromolecular substances including regulatory enzymes and other body proteins yielding more persistent changes in the direction of metabolism and rates of flow (Hochachka and Somero 1973, Smellie and Pennock 1976). Long-lived species may exhibit seasonal alterations in metabolic pathways keyed to periodicities in the environment such as photoperiod or temperature. They also may in each of these seasons adaptively respond to novel or irregularly occurring perturbations in their habitat.

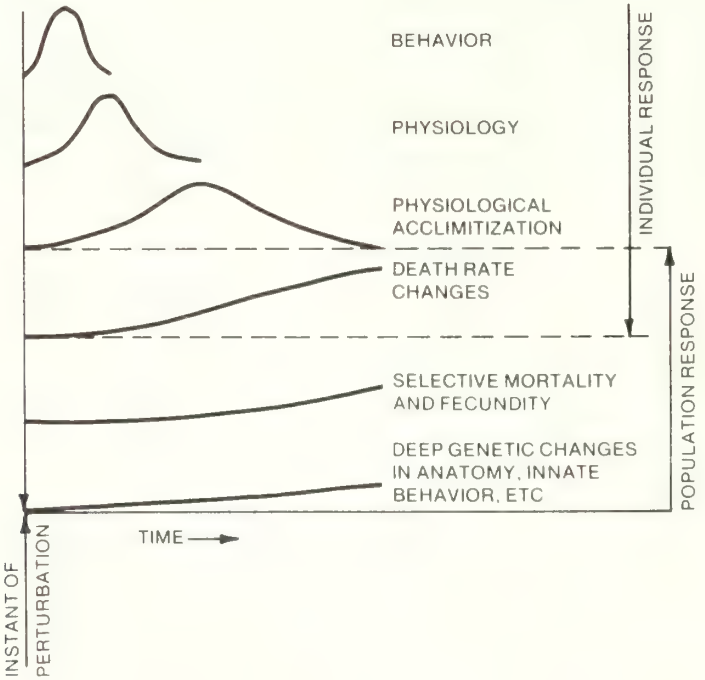

BEHAVIOR
PHYSIOLOGY
PHYSIOLOGICAL ACCLIMITIZATION
DEATH RATE CHANGES
SELECTIVE MORTALITY AND FECUNDITY
DEEP GENETIC CHANGES IN ANATOMY, INNATE BEHAVIOR, ETC
INDIVIDUAL RESPONSE
POPULATION RESPONSE
TIME
INSTANT OF PERTURBATION

Figure 1. Representation of the events that follow an environmental perturbation (Slobodkin and Rapoport 1974).

Application to these problems of the rapidly growing body of knowledge concerning adaptive metabolic pathways and their regulation is beginning to yield interesting results (Cahill et al. 1966, Bowden 1971, Krebs et al. 1971, Krebs 1972, Blowey et al. 1973, Le Resche et al. 1974, Payne et al. 1974, Andrews et al. 1975, Seal et al. 1975, Abler et al. 1976, Smellie and Pennock 1976, Seal et al. 1978a, 1978c). Inferences about duration of perturbations in habitat condition can be made from changes in metabolic and endocrine indicators with different rates of response to environmental change. These range from seconds (blood glucose, catecholamines, cortisol, and glucagon) to days (ketone bodies, nonesterified fatty acids, triiodothyronine, thyroxine, urea, and blood amino acids) to weeks (serum proteins) to months (red blood cell size and hemoglobin content). Thus, by measurement of the appropriate substrates, metabolites, enzymes, hormones, blood chemistries, hematology, serum proteins and their correlation with growth, reproduction, and survival it is conceivably possible to assess the quantity and composition of the food supply available to an animal over a period of time, the presence of disease, the impact of social factors, and the reproductive state.

It has proven mandatory, for successful interpretation of metabolic and endocrine data, to conduct controlled studies on animals held in captivity in order to establish appropriate baselines and determine the responses to perturbation which are characteristic of an individual species. It is the intention of this paper to illustrate these concepts in terms of controlled studies that have been conducted on white-tailed deer (Odocoileus virginianus) which demonstrate the feasibility of assessing nutritional intake from metabolic and endocrine changes and the feasibility of assessing disease status from changes in serum proteins and several metabolites. Some results from analyses of several wild populations of white-tailed deer are also presented.

For most species, data from captive groups of animals held under controlled conditions do not exist, consequently, it is also pertinent to examine the potential of these methods for direct application to field studies. This may be accomplished by comparison and contrast of differing populations of a given species which are observed to live on ranges of different kinds and perhaps quality. Also, comparisons may be made from one year to the next and correlated with the changing status of the population and the habitat. If these comparisons yield metabolic differences, then one may infer that the assays have potential for interpretation as indicators of the status of the animal populations and the condition of the habitat. Data illustrating such comparisons are presented here for the pronghorn antelope (Antilocapra americana), red fox (Vulpes vulpes), and timber wolf (Canis lupus).

CAPTIVE STUDIES OF THE WHITE-TAILED DEER

The experimental studies on captive white-tailed deer have been directed at collection of biological and biochemical data describing the normal pattern of events associated with growth, reproduction, seasonal changes, disease, the effects of handling, and changes associated with systematic manipulation of diet (Seal et al. 1972a, 1972b, McMillin et al. 1974, McMillin et al. 1978, Plotka et al. 1977a, 1977b, Seal et al., 1978b, 1978c).

Seasonal changes in growth, food intake, and metabolic status have been thoroughly documented in the Cervidae (Le Resche et al. 1974). These adjustments reflect seasonal changes in food availability and weather. They represent genetically based patterns which are keyed to periodic environmental changes. The amplitude or intensity of these periodic metabolic changes is tuned to the severity of the environmental change, as we shall see in some of the nutritional data from wild animals. One example of the seasonal changes is the correlated changes of testosterone, morphological characters, and antlerogenesis in the adult white-tailed deer buck (McMillin et al 1974, McMillin et al 1978). These animals exhibit a regular recurring cycle of antler growth and casting. It is associated with an annual cycle of testes size and serum testosterone levels. A detailed analysis (Figure 2) indicates a close association between these changes and the period of rut (McMillin et al. 1978). It is notable that the increases in weight and testes volume precede the sharp peaking of serum testosterone and that serum testosterone levels are actually declining at the time of breeding. Experimental analysis and field observations of the events associated with antlerogenesis have demonstrated that the timing of this phenomenon is synchronized by photoperiod. The growth of antlers and the duration of their retention are modulated by nutrition. The occurrence of puberty and perhaps the expression of breeding activity may be modulated by social factors.

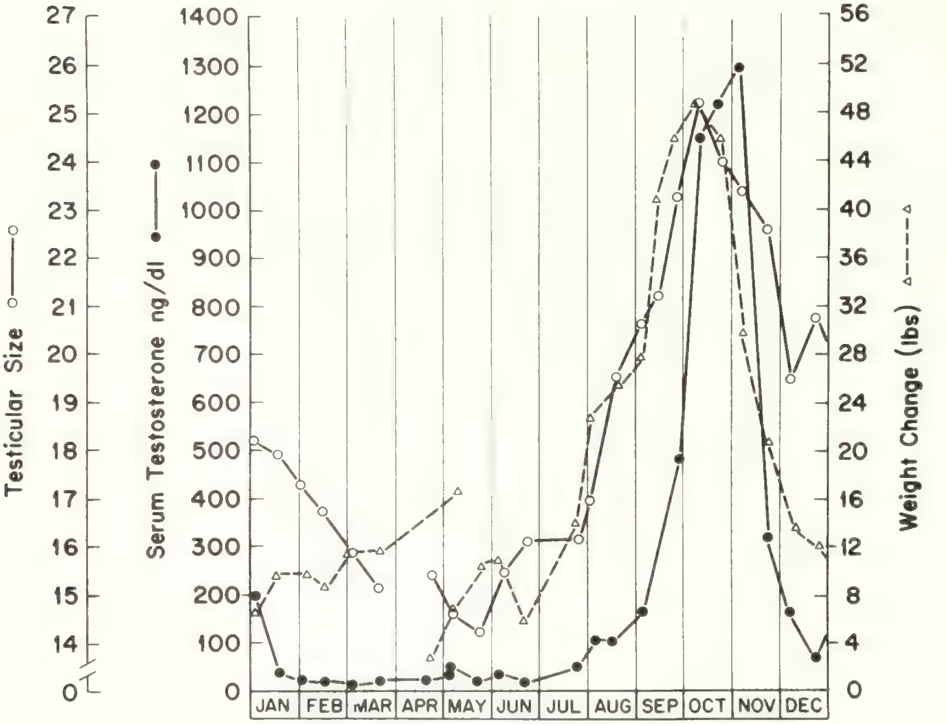


Figure 2. Annual cycle of changes in body weight, testicular size and serum testosterone in adult male white-tailed deer.

Proximate analysis of habitat condition is simplest at the extremes. When populations are high and appear in excellent condition as measured by body weight and productivity, then the judgment of good habitat is easily made. Conversely, the widespread occurrence of starvation deaths, poor fawn productivity, and early mortality can usually be associated with poor habitat or a combination of poor habitat and severe weather conditions. Between these extremes evaluations become considerably more difficult. Metabolic assessment would be of greatest value if it could provide a quantitative assessment of status rather than simply an identification of extremes. Experimental studies with domestic animals and man indicate that this should be possible (Cahill et al. 1966, Payne et al. 1974). Thus, studies are available indicating a quantitative relationship between serum urea levels (Figure 3) and nitrogen intake (Preston et al. 1965). Also, energy intake appears to be correlated with serum levels of nonesterified fatty acids or NEFA (Russel and Doney 1969).

We have been extending these studies in the white-tailed deer to include a wide range of simultaneous measurements of metabolites, chemistries, and hormone levels as well as dynamic studies of these substances. One such set of studies was a 2 x 2 factorial experiment varying energy protein intake of

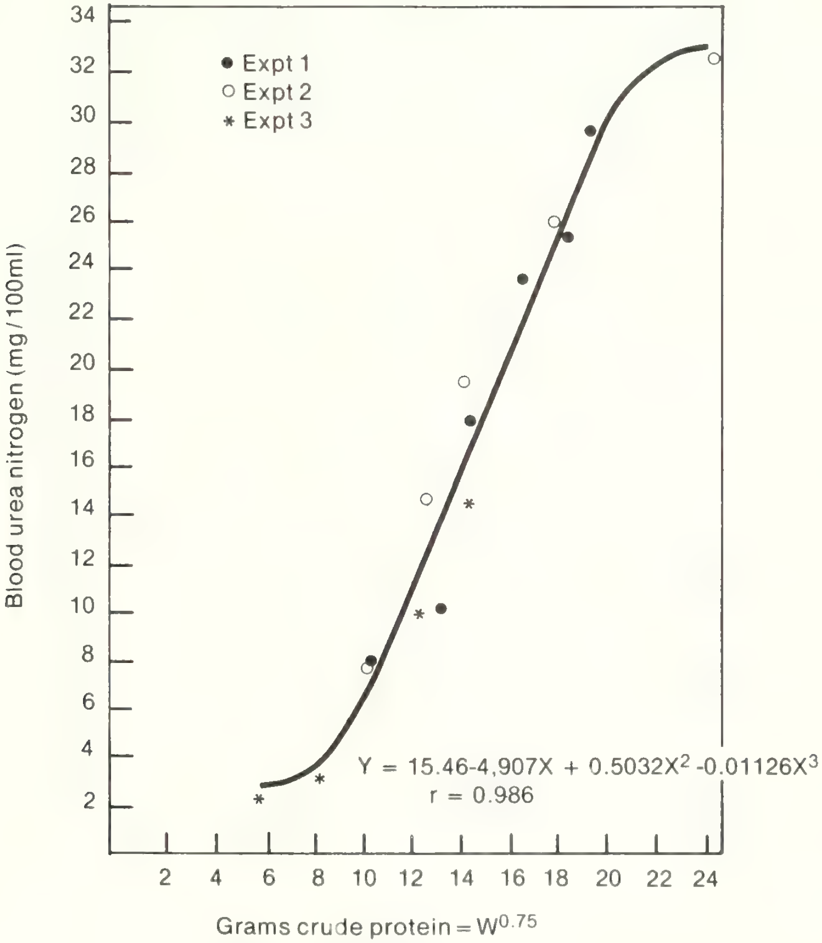


Figure 3. Blood urea nitrogen as affected by increasing protein intake (Preston et al., 1965).

the animals (Seal et al. 1978b). The four diets contained either high protein (16 percent of protein content), low protein (6 percent of protein content), and either moderate or low energy levels. Five animals in each of the four groups were maintained on the diet for 10 weeks. Results of blood assays on samples collected at the end of this period are described here. All comparisons were made by way of two-way analysis of variance with separation of protein and energy effects and identification of protein-energy interaction effects. There were significant effects of protein intake on hemoglobin levels and of protein and energy intake on numbers of red blood cells (Table 1).

Interestingly, there were no significant effects upon hematocrit (Hct) or packed cell volume (PCV). (The hematocrit has been recommended on a number of occasions as an assessment of condition for deer and other species of animals. Such studies have usually not included controls for seasonal effects, age, or mode of sample collection. It is likely in ruminants that reduced hematocrit will reflect only very severe nutritional deprivation or blood loss due to parasites.) Red cell parameters in fawns are also markedly affected by protein and energy content of diet, as evidenced by differences in mean corpuscular volume (MCV) or red cell size, mean corpuscular hemoglobin content (MCHC) and hemoglobin content per red cell (MCH) (Table 2). These effects tend to be persistent and require some time to become evident because red blood cells have a half-life of approximately 120 days. Thus, nutritional perturbations would have to persist for weeks to be reflected in these measures.

Serum urea nitrogen and serum nonesterified fatty acid (NEFA) levels are strongly related to protein and energy content of the diet respectively (Table 3). Thus, it should be possible to obtain an approximation of nitrogen

Table 1. Effects of Dietary Protein and Energy Content on Hematology of Deer Fawns

Diet group[a]	Hemoglobin g/dl	Hematocrit volume %	RBC $10^6/\mu l$
HP-ME[b]	17.5 ± 0.2[c]	53.4 ± 0.8	23.8 ± 0.5
HP-LE	17.6 ± 0.7	52.6 ± 1.8	20.5 ± 2.6
LP-ME	18.8 ± 0.5	52.5 ± 1.3	18.9 ± 0.1
LP-LE	19.4 ± 0.5	52.6 ± 1.0	13.4 ± 1.0
ANOVA[d] $p \leq$	0.006 (protein)	NS	0.0006 (protein) 0.006 (energy)

[a] High protein-moderate energy, HP-low energy, low protein-ME, LP-LE.

[b] N = 5 in each group.

[c] Mean ± standard error.

[d] Analysis of variance - two way.

Table 2. Effects of Protein and Energy Intake on Deer Red Cell Parameters

Diet group[a]	MCV fl	MCHC g/dl	MCH pg/rbc
HP-ME	22 ± 0.8	32.8 ± 0.4	7.3 ± 0.2
HP-LE	27 ± 2.6	31.8 ± 0.9	9.1 ± 1.1
LP-ME	28 ± 4.6	35.4 ± 0.7	10 ± 0.3
LP-LE	40 ± 3.0	36.8 ± 0.4	15 ± 1.2
ANOVA $\rho \leq$	0.0004 (protein) 0.001 (energy)	0.00002 (protein)	0.0001 (protein) 0.001 (energy)

[a] Conditions and analyses are the same as for Table 1.

Table 3. Effect of Protein and Energy Intake on Deer Serum Urea and NEFA

Diet group[a]	Serum urea N mg/dl	Serum NEFA μEg/l
X ± SE		
HP-ME	46 ± 2	242 ± 69
HP-LE	45 ± 2	667 ± 132
LP-ME	19 ± 0.8	284 ± 46
LP-LE	23 ± 2	459 ± 124
ANOVA $\rho \leq$	2×10^{-9} (protein)	0.008 (energy)

[a] Conditions and analyses are the same as for Table 1.

and energy intake from measurements of these two parameters. However, caution should be exercised in these interpretations since relative efficiency of reutilization of urea nitrogen by ruminants is a function of dietary energy intake (Kirkpatrick et al. 1975). Thus, it is possible on a given protein intake to develop quite different body weights and reproductive efficiencies as a function of energy intake. This point is demonstrated in this study by the fact that the animals on the HP-LE diet and LP-ME diets experienced the same weight gain despite a nearly three-fold difference in protein intake over a 10 week period.

Thus, no single assay is adequate for assessment of condition. As might be expected, there were a series of differences in hormone levels associated with these differences in diet. Serum levels of cortisol were related to energy, glucagon to protein, and insulin to energy intake (Table 4). The alterations in serum thyroid hormones are of particular interest (Table 5). Serum thyroxine levels showed a weak but significant relationship to protein intake. More interestingly, serum triiodothyronine or T_3 levels were strongly related to energy intake (Seal et al. 1978c). It appears possible that perturbations in environmental availability of energy may be sensitively monitored by the system responsible for regulation of T_3 production. Increases in serum related to energy intake (Seal et al., 1978c). It appears possible that perturbations in environmental availability of energy may be sensitively monitored by the system responsible for regulation of T_3 production. Increase in serum T_3 or T_3 production should result in an increase in metabolic rate and utilization of the increased energy intake. Conversely, a declining energy intake might result in a decreased metabolic rate with widespread ramifications for growth, reproduction, and behavior.

Identification of substances not affected by a given degree of nutritional alteration is as important as identifying those substances sensitive to nutritional changes. Within the limits of this particular study, we identified some 15 assays which did not appear to be affected by protein or energy intake (Table 6). Notably, serum albumin was not affected whereas we know that with more severe nutritional deprivation, levels of this protein will decrease (Olusi et al. 1975), as has been demonstrated in studies of wild reindeer (Eriksson and Valtonen 1974, Hove and Jacobsen 1975, Hyvarinen et al. 1975). Haptoglobin, fibrinogen, and white blood cells are acute phase reactants or respond to disease and trauma (Jarrett 1972, Seal et al. 1972a), so it is of interest that they are little affected by these nutritional alterations. The same is true for a series of enzymes which are frequently used as indicators of disease.

Disease, parasites, and various kinds of trauma are frequent events in wild populations. It would be of value to assess their incidence and severity. It is also necessary to establish their impact upon the metabolic and endocrine assays being used for assessment of nutritional condition (Franzmann 1972, Seal et al. 1972a). We have collected such data opportunistically as sick animals have been identified. We have also conducted systematic evaluations of parasite loads in several of our long-term experimental studies.

We had an opportunity to examine and study a group of fawns during a bout of illness associated with mastitis in the does and probable _E. coli_ enterotoxemia in the fawns. Data were collected during the period of illness and upon subsequent recovery. As might be expected (Table 7) there were significant elevations of white blood cells, and in particular neutrophils,

Table 4. Effects of Protein and Energy Intake on Deer Serum Hormones

Diet group[a]	Cortisol µg/dl	Glucagon pg/ml	Insulin µU/ml
HP-ME	2.0 ± 0.6	249 ± 50	33 ± 3
HP-LE	1.6 ± 0.5	468 ± 77	28 ± 2
LP-ME	2.2 ± 0.4	219 ± 27	33 ± 2
LP-LE	0.4 ± 0.4	313 ± 104	25 ± 1
ANOVA $\rho \leq$	0.031 (energy)	0.06 (protein)	0.025 (energy)

[a] Conditions and analyses are the same as for Table 1.

Table 5. Effect of Dietary Protein and Energy Content on Thyroid Hormones of Deer

Diet group[a]	Thyroxine µg/dl	Triiodothyronine ng/l
	$\bar{X}$ ± SE	
HP-ME	26 ± 1.3	391 ± 21
HP-LE	23 ± 1.6	310 ± 6
LP-ME	21 ± 0.9	394 ± 7
LP-LE	21 ± 2.0	304 ± 14
ANOVA $\rho \leq$	0.052 (protein)	0.00002 (energy)

[a] Conditions and analyses are the same as for Table 1.

Table 6. Assays not Affected by Dietary Protein and Energy Content in White-tailed Deer Fawns

Serum protein
Albumin
Gamma globulin
Haptoglobin
Fibrinogen
Hematocrit
White blood cells
Neutrophils
Lymphocytes
Potassium
LDH
HBDH
GGTP
SGOT
CO_2

Table 7. Effect on an Acute Infection on Leucocytes in Deer

Assay	Sick[a]	Recovered[a]	$\rho \leq$[b]
$\bar{X} \pm SE$			
White Blood Cells ($10^3/\mu l$)	4.5 ± 0.3	3.2 ± 0.2	0.001
Neutrophils ($10^3/\mu l$)	3.3 ± 0.2	2.2 ± 0.1	0.0002
Lymphocytes ($10^3/\mu l$)	1.4 ± 0.1	1.2 ± 0.1	NS

[a] N = 15

[b] Statistical comparisons were by Students "t" test.

during the period of illness. Serum albumin levels were low (Table 8) and serum haptoglobin levels (an acute phase reactant) were very strikingly elevated as were fibrinogen levels. Gamma globulin levels were not elevated during this period. Serum thyroxine (Table 9) levels were modestly but significantly depressed and serum triiodothyronine levels were very significantly depressed as well (Chertow et al. 1974). Serum cortisol levels were modestly elevated. Serum NEFA levels (Table 10) were significantly decreased during the illness but there was no change in serum glucose levels and urea levels were modestly but significantly depressed.

Therefore, it is clear, that for proper evaluation of many assays of interest for assessment of nutritional condition, an estimate of the presence or absence of disease must be made. We are fortunate in that numerous indicators, including the acute phase reactants and white blood cells, are available for detecting the presence of active disease and, hence, allow appropriate interpretation of alterations in metabolite and hormone levels.

FIELD STUDIES OF WHITE-TAILED DEER

We had available samples from two high density populations of free-ranging deer being studied to determine the mechanisms by which high densities were achieved and maintained, and for the study of the possible impact upon the physiology of these animals (Seal and Jones 1978). Comparison of urea and glucose data (Table 11) with control animals indicated that the dietary intake for one of these populations was relatively inadequate with respect to both protein and energy, whereas the other was comparable to our control animals. Despite this, the serum thyroxine levels in both of the high density herds were comparable and lower than the controls.

Further examination of these animals indicated that one of the herds contained a very high incidence of goiter (Table 12), since the mean thyroid weights of these animals were about three times the normal. Its proximity to the Great Lakes region places it in a geographical region of iodine deficiency. Collections of thyroids indicated that the average thyroid weights of this goitrous herd were approximately three times normal. Their serum thyroxine levels were one-half to one-third of control levels. Treatment of some of these animals with iodized oil resulted in a significant increase in serum thyroxine levels (Table 13) and a significant increase in testes weight. This study illustrates the potential impact of specific nutrient deficiencies as opposed to an overall nutritional deficiency and the potential for detection and analysis given the availability of adequate control data for comparison.

We have more recently compared a series of white-tailed deer populations relatively closely located to one another in northeastern Minnesota (Seal et al. 1978a). These observations are a part of a series of predator-prey relationship studies carried out by Dave Mech and his students in their area of intensive study of wolves. Animals are captured by trapping, netting, and radio-darting, blood samples collected and measurements taken, and then the radio-collared animals are released for study of movement patterns. Comparison of blood results from these four populations (Table 14) reveals that each can be differentiated from the other on the basis of blood differences. Thus, by analysis of variance there are significant differences, between populations, in numbers of red blood cells, red blood cell size and mean corpuscular hemoglobin content. These hematology differences indicate differences between populations

Table 8. Effects of an Acute Infection on
Serum Proteins in Deer

Assay	Sick[a]	Recovered[a]	$p \leq$[b]
$\bar{X} \pm$ SE			
Albumin (g/dl)	3.0 ± 0.1	3.7 ± 0.08	0.001
Haptoglobin (mg/dl)	216 ± 51	1 ± 0.05	0.0002
Fibrinogen (mg/dl)	602 ± 68	238 ± 12	0.0001
Gamma globulin (g/dl)	0.45 ± 0.03	0.45 ± 0.03	NS

[a] N = 15

[b] Statistical comparisons were by Students "t" test.

Table 9. Effects on an Acute Infection on
Serum Hormones in Deer

Assay	Sick[a]	Recovered[a]	$p \leq$[b]
$\bar{X} \pm$ SE			
Thyroxine (μg/dl)	18.7 ± 0.6	22.6 ± 0.8	0.0004
Cortisol (μg/dl)	3.1 ± 0.4	2.0 ± 0.6	
Triiodothyronine (ng/dl)	2984 ± 12	391 ± 21	0.001

[a] N = 15

[b] Statistical comparisons were by Students "t" test.

Table 10. Effects of an Acute Infection on
Metabolites in Deer

Assay	Sick[a]	Recovered[a]	$p \leq$[b]
$\bar{X} \pm$ SE			
NEFA (μEq/l)	144 ± 29	264 ± 60	0.001
Glucose (mg/dl)	150 ± 10	168 ± 5	NS
Urea (mg/dl)	39 ± 1.5	45 ± 2.2	0.05

[a] N = 15

[b] Statistical comparisons were by Students "t" test.

Table 11. Metabolic Comparisons of White-Tailed Deer on Adequate and Deficient Diets

Condition (N)	Thyroxine μg/dl	Urea mg/dl	Glucose mg/dl
Controlled diet (20)	17.0 ± 0.8[a]	25 ± 1.1	169 ± 22
Depleted range (30)	9.4 ± 0.8	13 ± 1.2	256 ± 30
Goitrous herd (20)	9.6 ± 1.0	21 ± 1.5	130 ± 18

[a] Mean ± standard error.

Table 12. Goiter and Iodine Deficiency in A White-Tailed Deer Population

Group (N)	Thyroid weight mg/kg	Serum thyroxine μg/dl
$\bar{X}$ ± SE		
Adult		
Female (10)	140 ± 12	9 ± 1.2
Male (10)	126 ± 10	9 ± 0.8
Fawn		
Female (10)	84 ± 12	8 ± 1
Male (10)	82 ± 12	7 ± 0.8

Table 13. Effects of Iodine Supplementation on Fawns From Goitrous Deer Herd

Fawns	Untreated (10)[a]	Treated (5)	$p \leq$[b]
Thyroxine (g/dl)	8.3 ± 0.80[c]	10.6 ± 1.1	0.02
Testes (g)	8.5 ± 0.09	11.4 ± 0.80	0.05

[a] Number of deer.

[b] Compared with "t" test.

[c] Mean ± standard error.

Table 14. Hematology Differences Between Local Minnesota Deer Populations

Assay	Lutsen (10)[a]	Bushel (7)	Kawishiwi(7)	Winton (8)	$p \leq$
RBC	11 ± 0.8	9.2 ± 0.3	12 ± 0.9	11 ± 0.4	0.03
MCV	41 ± 2	47 ± 3	32 ± 3	38 + 2	0.008
MCHC	35.5 ± 0.7	37.6 ± 0.7	38.6 ± 0.4	38.6 ± 1	0.009

[a] Number of deer.

with respect to protein and energy intake. This is borne out by the data on serum levels of urea, NEFA, cholesterol and thyroxine (Table 15). For example, the Bushel Lake population has low urea levels and high NEFA levels, indicating a diet with both low protein and low energy content. It should be noted that in these analyses effects of age, sex, date of collection and presence of disease have been considered. Consideration of these results is leading to further analysis of differences in habitat for these four populations as well as an evaluation of their relationship to predation. Most importantly, they demonstrate that it is possible to differentiate local populations in terms of nutritional status and provide a basis for further analysis of habitat differences.

FIELD STUDIES OF PRONGHORN ANTELOPE

Pronghorn antelope occupying the winter range on the eastern Snake River plain disperse to three separate summer ranges. Blood samples were obtained from animals representing each of these three populations, while on their winter ranges. Comparisons of blood assay data between the three populations revealed an extensive series of highly significant differences. Most could be suggested to be due to nutrition (Seal and Hoskinson 1978). Thus (Table 16) there were highly significant differences in serum urea levels with the Little Lost herd having levels more than twice that of the other two herds. The other two herds also differ. The Little Lost herd had higher triglyceride and lower thyroxine levels, while the Crooked Creek herd had the lowest cortisol levels. Differences in serum enzymes were also evident (Table 17). Thus, the fawns of the Little Lost herd with high urea levels had very high alkaline phosphatase levels, probably reflecting a continued growth in these animals as the result of superior nutrition. Interestingly enough, there were also sex differences in alkaline phosphatase levels with adult males having higher levels than adult females. The reason for the significant difference between the two groups of adult females is not known. A partial basis for these differences between herds is that the Little Lost herd traverses agricultural land in its migration into its winter range and is able to graze extensively upon crops.

FIELD STUDIES OF RED FOX

Samples were collected from red fox pups in spring and fall from populations in Iowa and Illinois (Storm et al. 1976, Seal and Storm 1978). These populations are separated by the Mississippi River. They differ in population density and in average litter size. The basis for these population differences is not known. Comparisons of results from blood assays revealed a wide range of differences between the populations in both seasons. Thus, the Iowa population (Table 18) had higher hemoglobin levels, more red cells, and a higher hematocrit in spring and fall. These differences are significant. There is also notable here a significant seasonal difference with higher levels in the fall.

Interestingly enough, comparison of serum urea and glucose levels revealed no significant differences between the populations although there are significant seasonal changes (Table 19). Therefore, we need to search elsewhere than protein and energy intake for the basis of the hematology differences in these animals. Measurements of serum calcium and phosphorus demonstrate further significant differences between these populations (Table 20). Thus, the Iowa

Table 15. Serum Chemistry Differences Between Local Minnesota Deer Populations

Assay	Lutsen (10)[a]	Bushel (7)	Kawishiwi(7)	Winton (8)	$p \leq$
Urea (mg/dl)	16 ± 1	8 ± 1	10 ± 2	15 ± 2	0.01
NEFA (μEq/l)	540 ± 102	656 ± 144	329 ± 89	237 + 30	0.01
Cholesterol (mg/dl)	68 ± 4	67 ± 3	90 ± 7	65 ± 4	0.003
Thyroxine (μg/dl)	9 ± 1	7 ± 0.4	13 ± 2	9 ± 1	0.02

[a] Number of deer.

Table 16. Serum Metabolite and Hormone Differences Between Three Idaho Pronghorn Antelope Populations

Assay	Little Lost[a](23)	Birch Creek (25)	Crooked Creek (37)	$p \leq$
Serum urea (mg/dl)	44 ± 1.8	11.3 ± 0.6	18.6 ± 0.7	0.0001
Triglycerides (mg/dl)	182 ± 16	93 ± 10	98 ± 5	0.0001
Thyroxine (μg/dl)	5.0 ± 0.4	7.2 ± 0.6	6.4 ± 0.3	0.0003
Cortisol (μg/dl)	6.1 ± 0.3	5.8 ± 0.4	4.3 ± 0.3	0.0001

[a] Number of antelope.

Table 17. Comparison of Pronghorn Antelope Alkaline Phosphatase Levels in Terms of Age, Sex, and Location

Location	Adult Male[a]	Adult Female[a]	Fawns[a]	ρ≤
Little Lost			200 ± 29 (8)	0.001
	72 ± 6.5 (10)[b]	50 ± 6.7 (11)		
Birch Creek			91 ± 19 (7)	0.02
Crooked Creek	68 ± 6.8 (9)	35 ± 3.0 (17)	81 ± 4.4 (10)	0.0001

[a] The unit of measurement is I.U./l.

[b] Number of antelope.

Table 18. Hematology Comparisons of Red Fox Pups From Two Populations

	$\bar{X}$ ± S.E.		
Group (N)	Hemoglobin mg/dl	Red Cells $10^6/\mu l$	Hematatocrit vol.%
$\bar{X}$ ± SE			
Spring			
Illinois (28)	10.9 ± 0.2	6.4 ± 0.1	36 ± 0.6
Iowa (22)	12.4 ± 0.3	7.5 ± 0.1	39 ± 0.6
Fall			
Illinois (26)	16.9 ± 0.3		49 ± 1
Iowa (18)	18.2 ± 0.4		56 ± 2

Table 19. Serum Chemistries in Red Fox Pups From Two Populations

Group (N)	Urea mg/dl	Glucose mg/dl
$\bar{X} \pm$ SE		
Spring		
Illinois (28)	36 ± 2	141 ± 5
Iowa (22)	37 ± 2	141 ± 8
Fall		
Illinois (26)	23 ± 2	162 ± 10
Iowa (18)	25 ± 1	182 ± 11

Table 20. Serum Electrolytes in Fox Pups From Two Populations

Group (N)	Calcium mg/dl	Phosphorus mg/dl
$\bar{X} \pm$ SE		
Spring		
Illinois (28)	8.8 ± 0.2	9.0 ± 0.1
Iowa (22)	9.7 ± 0.2	8.8 ± 0.2
Fall		
Illinois (26)	7.8 ± 0.2	4.0 ± 0.3
Iowa (18)	8.4 ± 0.3	6.4 ± 0.3

population had persistently higher serum calcium levels and higher serum phosphorus levels in the fall. Overall, these results suggest we should look further for differences in parasite loads or availability of iron and perhaps several vitamins such as folic acid and B_{12}. Such data might then point the way for more detailed analysis of habitat differences.

FIELD STUDIES OF THE TIMBER WOLF

Studies of a thinly distributed, free-ranging, and widely dispersed predator species such as the timber wolf present a special kind of challenge. Dave Mech and his co-workers have collected samples from all animals trapped in his studies over the past 6 years. One set of results from the wild animals of especial interest has been the changes occurring in pups over a 3-year period in association with changes in population trends and in food availability (Seal et al. 1975, Van Ballenberghe and Mech 1975).

The study area is in northeastern Minnesota in the Superior National Forest. This area has been characterized by progressive maturation of the forest and a decline in white-tailed deer population over a period of years. Particularly marked changes in the deer population occurred during the severe winters of 1970-71 and 1971-72. We analyzed samples obtained from wolf pups to determine if these changes were reflected in the physiology of these animals. Since in the overall comparisons we found a series of significant differences between the sexes, we made comparisons between the years of 1970 and 1972 with respect to the male pups (Table 21).

There were significant differences between 1970 and 1972 in white blood cell counts, red blood cells, red blood cell size, and serum proteins. The 1972 animals had lower levels of WBC and RBC, and larger RBC's. Our studies on captive animals indicate that well nourished animals have MCV or red blood cell sizes around 71 fl. Therefore, the value of 91 fl in the 1972 animals is a significant elevation in comparison with the 1970 animals or with well nourished control animals. Significant serum chemistry differences between the 2 years (Table 22) included higher levels of the serum enzyme SGOT (AAT) in 1972 and lower levels of cholesterol, urea, and serum thyroxine. These data are compatible with significantly poorer nutrition in the 1972 pups.

Another index of differences between the years was found when all data were analyzed for significantly deviant assay results (Table 23). The 1970 samples revealed one abnormal test result in one of 14 animals examined. In 1971, 2 of 7 animals tested had 4 abnormal test results, whereas in 1972 10 of 11 animals examined had a total of 27 abnormal test results. Thus, it would appear that these animals showed evidence of significantly reduced nutrition and significantly increased vulnerability to metabolic abnormalities that might be attributed to either disease or other nutritional deficiencies. Associated with these changes were significantly decreased average weights of the 1972 pups, corroborating the change in nutritional status. There was also evidence of decreased pup survival and deteriorating social organization in these animals which are interpreted to reflect decreased prey availability and a resultant nutritional stress upon these animals.

Table 21. Hematology Differences in Male Wolf Pups,
1970 vs. 1972 Animals

Assay	1970 (9)[a]	1972 (8)	$p \leq$
	$\bar{X} \pm SE$		
WBC (10^3/µl)	16.4 ± 1.6	9.5 ± 1.9	0.02
RBC (10^6/µl)	5.3 ± 1.5	4.1 ± 0.25	0.001
MVC (fl)	76 ± 2	91 ± 4	0.005
A/G	0.99 ± 0.04	1.19 ± 0.07	0.02

[a] Number of wolf pups.

Table 22. Chemistry Differences in Male Wolf Pups,
1970 vs. 1972 Animals

Assay	1970 (9)[a]	1972 (8)	$p \leq$
	$\bar{X} \pm SE$		
SGOT (mU/ml)	60 ± 5	105 ± 5	0.001
Cholesterol (mg/dl)	247 ± 11	209 ± 12	0.05
Urea (mg/dl)	23 ± 3	15 ± 1.5	0.05
Thyroxine (µg/dl)	4.2 ± 0.5	3.0 ± 0.4	0.02

[a] Number of wolf pups.

Table 23. Abnormal Assay Results From Wolf Pups

Year	Animals(N)	Tests
1970	1 (14)	1
1971	2 (7)	4
1972	10 (11)	27

The results presented here represent a sampling of our studies which now include data on black bear (*Ursus americanus*), polar bear (*Thalarctos maritimus*), brown bear (*Ursus middendorffi*), moose (*Alces alces*), grouse (*Bonasa umbellus*), pheasant (*Phasianus colchicus*), several species of pinnipeds (Seal et al. 1970, 1971, Seal 1976a, 1976b), and other populations of the timber wolf and white-tailed deer. Similar studies have been published on moose (LeResche et al. 1974), mule deer (*Odocoileus hemionus*) (Anderson et al. 1970, 1972), reindeer (*Rangifer tarandus*) (Eriksson and Valtonen 1974, Hove and Jacobsen 1975, Hyvarinen et al. 1975), and bighorn sheep (*Ovis canadensis*) (Franzmann 1972). These results of these studies suggest to us that it is possible to make some assessment of habitat status by analysis of metabolic and endocrine parameters in wild populations. Furthermore, it seems likely that the results are not trivial. Thus, not only can we provide correlates with the extremes, readily documented by striking changes in demographic characteristics or gross physical condition of the animals, but it is possible to detect more subtle differences between local habitats. This suggests continued applications of these techniques, in close-knit collaborative studies between the field biologist and the biochemist, can produce results leading to a new understanding of the relationship between animals and their habitats. The physiological data may be able to provide clues as to habitat differences not previously suspected and, in addition, provide the means for quantitative assessment of the nutritional adequacy of the habitat with respect to the species of interest. Furthermore, it is my anticipation, from the results already available, that it will be possible to suggest a rather simple battery of tests for survey of individual populations of species for whom some baseline data are available. This then might provide an objective basis for evaluation of the results of habitat manipulation more rapidly, and on a continuing basis, than is currently possible from utilization of standard demographic techniques or from efforts at direct habitat evaluation.

ACKNOWLEDGEMENTS

The author acknowledges the considerable assistance of L. J. Verme and J. J. Ozoga, Cusino Wilderness Research Station, Department of Natural Resources, Shingleton, Michigan; R. Hoskinson, Department of Entomology, Fish and Wildlife, University of Minnesota, St. Paul; L. D. Mech, U.S. Fish and Wildlife Service, North Central Forest Experiment Station, St. Paul, Minnesota; M. Nelson, Department of Entomology, Fish, and Wildlife, University of Minnesota, St. Paul; G. Storm, Pennsylvania Cooperative Wildlife Research Unit, Pennsylvania State University, University Park; W. Jones, U.S. Fish and Wildlife Service, Federal Building, Twin Cities, Minnesota; J. M. McMillin, Department of Medicine, University of South Dakota, Sioux Falls; and P. D. Karns, Minnesota Department of Natural Resources, Grand Rapids.

LITERATURE CITED

Abler, W.A., D.E. Buckland, R.L. Kirkpatrick, and P.F. Scanlon. 1976. Plasma progestins and puberty in fawns as influenced by energy and protein. J. Wildl. Manage. 40(3):442-446.

Anderson, A.E., D.E. Medin, and D.C. Bowden. 1970. Erythrocytes and leukocytes in a Colorado mule deer population. J. Wildl. Manage. 34(2):389-406.

Anderson, A.E., D.E. Medin, and D.C. Bowden. 1972. Blood serum electrolytes in a Colorado mule deer population. J. Wildl. Dis. 8:183-190.

Andrews, R.V., K. Ryan, R. Strohbehn, and M. Ryan-Kline. 1975. Physiological and demographic profiles in brown lemmings during their cycle of abundance. Physiol. Zool. 48(1):64-83.

Blowey, R.W., D.W. Wood, and J.R. Davis. 1973. A nutritional monitoring system for dairy herds based on blood glucose, urea and albumin levels. Vet. Rec. 92:691-696.

Bowden, D.C. 1971. Non-esterified fatty acids and ketone bodies in blood as indicators of nutritional status in ruminants. Can. J. Anim. Sci. 51(1):1-13.

Cahill, G.F., M.G. Herrera, A.P. Morgan, J.S. Soeldner, J. Steinke, P.L. Levy, G.A. Reichard, Jr., and D.M. Kipnis. 1966. Hormone-fuel interrelationships during fasting. J. Clin. Invest. 45:1751-1769.

Chertow, B.S., G.S. Motto, and J.H. Shah. 1974. A biochemical profile of abnormalities in hypothyroidism. Am. J. Clin. Pathol. 61:785-788.

Eriksson, L., and M. Valtonen. 1974. Seasonal changes in renal urea concentration in the reindeer (Rangifer tarandus L.). Ann. Zool. Fennici 11: 200-203.

Franzmann, A.W. 1972. Environmental sources of variation of bighorn sheep physiologic values. J. Wildl Manage. 36(3):924-932.

Hochachka, P.W., and G.N. Somero. 1973. Strategies of Biochemical Adaptation. W.B. Saunders Co., Philadelphia, Pennsylvania.

Hove, K., and E. Jacobsen. 1975. Renal excretion of urea in reindeer: effect of nutrition. Acta Vet. Scand. 16:513-519.

Hyvarinen, H., T. Helle, R. Vayrynen, and P. Vayrynen. 1975. Seasonal and nutritional effects on serum proteins and urea concentration in the reindeer (Rangifer tarandus tarandus L.). Br. J. Nutr. 33:63-72.

Jarrett, I.G. 1972. A polymeric form of hemoglobin-binding protein in sheep following metabolic and hormonal disturbance. Aust. J. Biol. Sci. 25:941-948.

Kirkpatrick, R.L., D.E. Buckland, W.A. Abler, P.F. Scanlon, J.B. Whelan, and H.E. Burkhard. 1975. Energy and protein influences on blood urea nitrogen of white-tailed deer fawns. J. Wild. Manage. 39(4):692-698.

Klein, D.R. 1970. Food selection by North American deer and their response to over-utilization of preferred plant species, pp. 25-46. A. Watson (ed.), *In* Animal Populations in Relation to their Food Resources, Blackwell Sci. Publ. Ltd., Oxford.

Krebs, H.A. 1972. Some aspects of the regulation of fuel supply in omnivorous animals. Adv. Enzyme Regulation 10:397-420.

Krebs, H.A., D.H. Williamson, M.W. Bates, M.A. Page, and R.A. Hawkins. 1971. The role of ketone bodies in caloric homeostasis, pp. 387-409. *In* Adv. Enzyme Regulation 9.

LeResche, R.E., U.S. Seal, P.D. Karns, and A.W. Franzmann. 1974. A review of blood chemistry of moose and other Cervidae with emphasis on nutritional assessment. Nat. Can. 101:263-290.

McMillin, J.M., U.S. Seal, K.D. Keenlyne, A.W. Erickson, and J.E. Jones. 1974. Annual testosterone rhythm in the adult white-tailed deer (*Odocoileus virginianus borealis*). Endocrinology 94:1034-1040.

McMillin, J.M., U.S. Seal, and P.D. Karns. 1978. Seasonal changes in body characters and pituitary-gonadal activity in male white-tailed deer. (manuscript in preparation).

Olusi, S.O., H. McFarlane, B.O. Osunkoya, and H. Adesina. 1975. Specific protein assays in protein-calorie malnutrition. Clin. Chim Acta 62: 107-116.

Payne, J.M., G.J. Rowlands, R. Manston, S.M. Dew, and W.H. Parker. 1974. A statistical appraisal of the results of the metabolic profile tests on 191 herds in the B.V.A./A.D.A.S. joint exercise in animal health and productivity. Br. Vet. J. 130:34-44.

Perry, J.S. and I.W. Rowlands. 1973. The Environment and Reproduction in Mammals and Birds. Blackwell Sci. Publ. Ltd., Oxford.

Plotka, E.D., U.S. Seal, G.C. Schmoller, P.D. Karns and K.D. Keenlyne. 1977a. Reproductive steroids in the white-tailed deer (*Odocoileus virginianus borealis*). I. Seasonal changes in the female. Biol. Reprod. 16:340-343.

Plotka, E.D., U.S. Seal, J.L. Verme, and J.J. Ozoga. 1977b. Reproductive steroids in the white-tailed deer (*Odocoileus virginanus borealis*). II. Progesterone and estrogen levels in peripheral plasma during pregnancy. Biol. Reprod. 17:78-83.

Preston, R.L., D.D. Schnakenberg, and W.H. Pfander. 1965. Protein utilization in ruminants. I. Blood urea nitrogen as affected by protein intake. J. Nutr. 86:281-288.

Russel, A.J.F., and J.M. Doney. 1969. Observations on the use of plasma free fatty acid concentrations in the determination of maintenance requirements of sheep. J. Agric. Sci. Camb. 72:59-63.

Seal, U.S. 1976a. Identification of biochemical and endocrine indicators of the nutritional, reproductive and disease status of free-ranging marine mammal populations. Prepared for the Marine Mammal Commission.

Seal, U.S. 1976b. Application of biochemical genetic methods to the analysis of genetic diversity and isolation of populations of marine mammal species. Prepared for the Marine Mammal Commission.

Seal, U.S., A.W. Erickson, D.B. Siniff, and R.J. Hofman. 1970. Biochemical, population genetic, phylogenetic and cytological studies of Antarctic seal species. pp. 77-95 *In* Symp. Antarctic Ice and Water Masses, Tokyo.

Seal, U.S., A.W. Erickson, D.B. Siniff, and D.R. Cline. 1971. Blood chemistry and protein polymorphisms in three species of Antarctic seals (*Lobodon carcinophagus*, *Leptonychotes weddelli*, and *Mirounga leonina*), pp. 181-192. *In* W.H. Burt (ed.), Antarctic Pinnipedia 18, Am. Geophys. Union, Washington, D.C.

Seal, U.S., J.J. Ozoga, A.W. Erickson, and L.J. Verme. 1972a. Effects of immobilization on blood analyses of white-tailed deer. J. Wildl. Manage. 36(4):1034-1040.

Seal, U.S., L.J. Verme, J.J. Ozoga, and A.W. Erickson. 1972b. Nutritional effects on thyroid activity and blood of white-tailed deer. J. Wildl. Manage. 36(4):1041-1052.

Seal, U.S., L.D. Mech, and V. Van Ballenberghe. 1975. Blood analyses of wolf pups and their ecological and metabolic interpretation. J. Mammal. 56(1): 64-75.

Seal, U.S., and G. Storm. 1978. Metabolic comparisons of red fox pups from two populations during spring and fall. (manuscript in preparation).

Seal, U.S., and R. Hoskinson. 1978. Metabolic indicators of habitat differences in three populations of pronghorn antelope. (manuscript submitted)

Seal, U.S., and W. Jones. 1978. Goiter in a white-tailed deer population. (manuscript in preparation).

Seal, U.S., M. Nelson, and L.D. Mech. 1978a. Metabolic indicators of habitat differences in local deer populations. (manuscript submitted)

Seal, U.S., L.J. Verme, and J.J. Ozoga. 1978b. Relative effects of dietary protein and energy on metabolic patterns of white-tailed deer. (manuscript submitted)

Seal, U.S., L. Verme. J. Ozoga, and J.M. McMillin. 1978c. The effect of dietary protein and energy content on serum concentration of triiodothyronine, thyroxine, urea nitrogen, nonesterified fatty acids and body weight changes of white-tailed deer fawns. (*Odocoileus virginianus borealis*). (manuscript submitted for publication).

Slobodkin, L.B., and A. Rapoport. 1974. An optimal strategy of evolution. Quart. Rev. Biol. 49(3):181-200.

Smellie, R.M.S., and J.F. Pennock. 1976. Biochemical Adaptation to Environmental Change. The Biochemical Soc., London. 240 pp.

Stearns, S.C. 1976. Life-history tactics: A review of the ideas. Quart. Rev. Biol. 51(1):3-47.

Storm, G.L., R.D. Andrews, R.L. Phillips, R.A. Bishop, D.B. Siniff, and J.R. Tester. 1976. Morphology, Reproduction, Dispersal, and Mortality of Midwestern Red Fox Populations. Wild. Mono. 49. The Wildl. Soc., Inc. 81 pp.

VanBallenberghe, V., and L.D. Mech. 1975. Weights, growth, and survival of timber wolf pups in Minnesota. J. Mammal. 56(1):44-63.

VanValen, L. 1973. Pattern and the balance of nature. Evol. Theory 1(1): 31-47.

VanValen, L. 1976. Energy and evolution. Evol. Theory 1(7):179-229.

Watson, A. 1970. Animal Populations in Relation to their Food Resources. Blackwell Sci. Publ., Inc., Oxford.

Wetzel, J.F., J.R. Wambaugh, and J.M. Peek. 1975. Appraisal of white-tailed deer winter habitats in northeastern Minnesota. J. Wildl. Manage. 39(1):59-66.

A DATA COMPILATION PROGRAM FOR WETLAND EVALUATION

J.K. Dueker and T.W. Haislip, Jr.
Beak Consultants Incorporated
317 South West Alder Street
Portland, Oregon 97204

Abstract: A compilation program was designed to select, organize, and present biological data relevant to wetland evaluation. A test of this program was conducted on data from the Harney Basin area of Oregon. From this test an instruction manual was developed for reviewers of biological value data. This manual explains the procedures, forms, and codes to be used in gathering data and incorporate them into the recommended data management system.

INTRODUCTION

The U.S. Fish and Wildlife Service intends to conduct a National Wetland Inventory, and as part of this inventory they desire a method of evaluating wetland resources to better preserve and manage this important habitat. Beak Consultants Incorporated was contracted by the U.S. Fish and Wildlife Service to develop a conceptual system for evaluating the wetlands of the United States using a biological approach. Other approaches such as social, economic, hydrological or land and resource use, were not included but they could be integrated into the program in the future.

The goal of a wetland evaluation system is to present values of wetlands in a standardized manner that will allow accurate, efficient, and comprehensive assessments. Ideally this would involve a synthesis of data into indices, thereby reducing complexity and simplifying the evaluation process. Such a synthesis involves development of criteria, assignment of worth, and must reflect a consensus of opinion. However, the very basic step of accumulating data must be completed, before this process can be designed and applied. The manner in which these basic data are obtained and organized will strongly influence the nature of the synthesis process and its resulting values.

Our approach was first to determine if an appropriate system of biological values had already been designed. There was no satisfactory system so we developed a compilation program that selected, organized, and presented biological data in a way that best prepared it for eventual synthesis and evaluation. A test of the compilation program was then conducted on a data-rich wetland. Finally a search for computer data management systems was conducted to adequately meet the requirements of the National Wetlands Inventory.

The compilation program was tested on biological data from the Harney Basin area of Oregon which includes the Malheur National Wildlife Refuge. An instruction manual for reviewers of biological value data was developed which explains the procedures, forms, and codes to be used in gathering data and incorporating it into the system.

SEARCH FOR VALUES

We searched for established wetland values and evaluation systems prior to developing a wetland data compilation program that would interface with the National Wetlands Classification System. This search included a thorough review of published and unpublished data, the ideas and discussions of the National Wetland Classification Workshops, and a questionnaire that was distributed at the second workshop.

Descriptions of the literature search, workshops, and questionnaires will not be presented here but a bibliography at the end of this paper of the important literature reviewed during this search is included.

The criteria used to determine the applicability of existing evaluation systems were that they be biologically oriented, complement the National Wetlands Classification System, and have computer data management capability. The search for values indicated that there were no existing systems which fulfilled the criteria necessary to evaluate wetlands of the United States, thus we developed such a program.

THE DATA COMPILATION PROGRAM

The compilation program is an organized approach to handling a wide range of biological parameters associated with the various wetlands in the United States. The program was developed around the concept of a hierarchical set of data storage positions or "pigeonholes" that could be accessed in a manner that is both versatile and selective. A general outline of the proposed data organization is presented in Figure 1. A more specific demonstration of the system's character is shown by the data recording sheets and the trial output presented later in this paper.

The development of the biological system was influenced primarily by the anticipated nature of the data, the needs of the eventual users, and the need for a format that could be processed by computer. Most data exist as specific information about individual species which is amenable to a "pigeonhole" arrangement of data, therefore, the system was designed to accept and handle such data. Allowances were also made for accepting specific and qualitative data such as species lists or general observations. These may, however, present problems with future aggregation efforts.

The anticipated needs of the user helped to establish the desired classes of information and their associated measures as well as the nature of the output and level of aggregation. A selection of the possible data types was made to insure that the system remained manageable and practical. The system reflects our judgment on the type of data to be entered and was designed to handle information useful to both wetland managers and research scientists.

We assumed it would be desirable to handle groups of species in output from the system especially when synthesizing data. However, the system is designed to allow the creation of vegetative groups as they become necessary. The animal groups and subgroups were selected on their

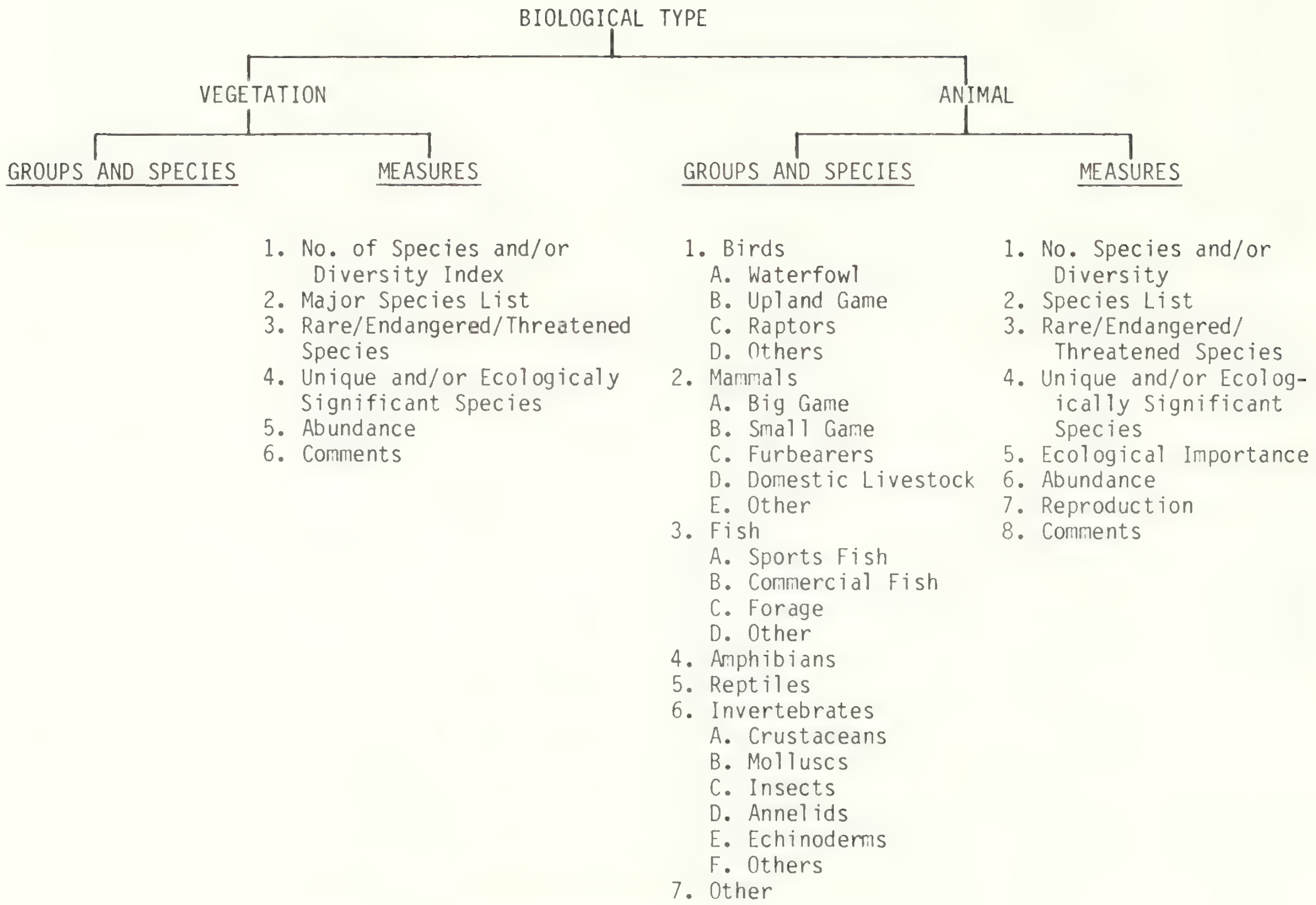


Figure 1. Proposed biological data organization.

natural habitat affinities, their economic value, and the likelihood of their usefulness in wetland evaluation. They include all major vertebrate groups, and most invertebrate groups of interest.

The selected measures represent the kinds of numerical information most likely available in the literature as well as some of those which will be commonly used for future evaluation and management of wetlands. However, the present system does not include all of the potentially useful measures suggested for future studies. These measures can be added when their usefulness is better defined.

The categories shown in the outline (Figure 1) are quite general. In actual operation of the system, the data are recorded in the same specific units as they occur in the source. A comment category was included for both vegetation and animal measures in order to handle useful, qualitative data not readily assigned to existing categories.

The biological organization is designed to be integrated with the draft wetland classification system. Figure 2 shows our view of the relationship between the two systems. After reviewing the classification system and considering existing data, we decided that two additional levels (Wetland Unit, and Location) were needed between the province and ecological class levels. We believe that data are most likely to be associated with a management or wetland unit and often to a specific location within that unit. Our trial compilation of data amply confirmed this belief. In fact, most of the data recorded was identified only to the unit without specifying any of the ecological or habitat levels. Assignment of data to the wetland unit offered a great deal of flexibility while still maximizing the precision of the data. However, we felt that biological data might be available and/or requested at any of the hierarchical levels of the classification scheme. Therefore, the data format was standardized in a manner that would allow input and aggregation at any given level.

TRIAL COMPILATION

SITE SELECTION

The data compilation program was tested to determine if it was truly functional. We needed a data-rich sample wetland, with a variety of wetland types for this test. In order to simplify logistics, a wetland near our Portland, Oregon, office was sought. A vareity of State and Federal fish and wildlife personnel, knowledgeable in the region's wetlands, were contacted. They were asked for opinions about which wetlands met the needed criteria. After assessing these opinions, and those of several experienced BEAK personnel, Harney Basin of eastern Oregon was selected. Most of the wetland in the basin is within Malheur National Wildlife Refuge. Harney Basin contains very large expanses of all three nonmarine wetland ecological systems and is noted for its abundant and diverse resources, especially birds. The refuge and the entire basin are currently under investigation by the Division of Ecological Services of the U.S. Fish and Wildlife Service in addition to the standard inventories conducted as part of the refuge management program. Further, a consortium of Northwest universities and colleges operates the Malheur Environmental Field Station (MEFS), located adjacent to the refuge, which sponsors biological research in the area. The wetlands of Harney Basin, and especially Malheur Refuge, offered a good model with which to develop the compilation program.

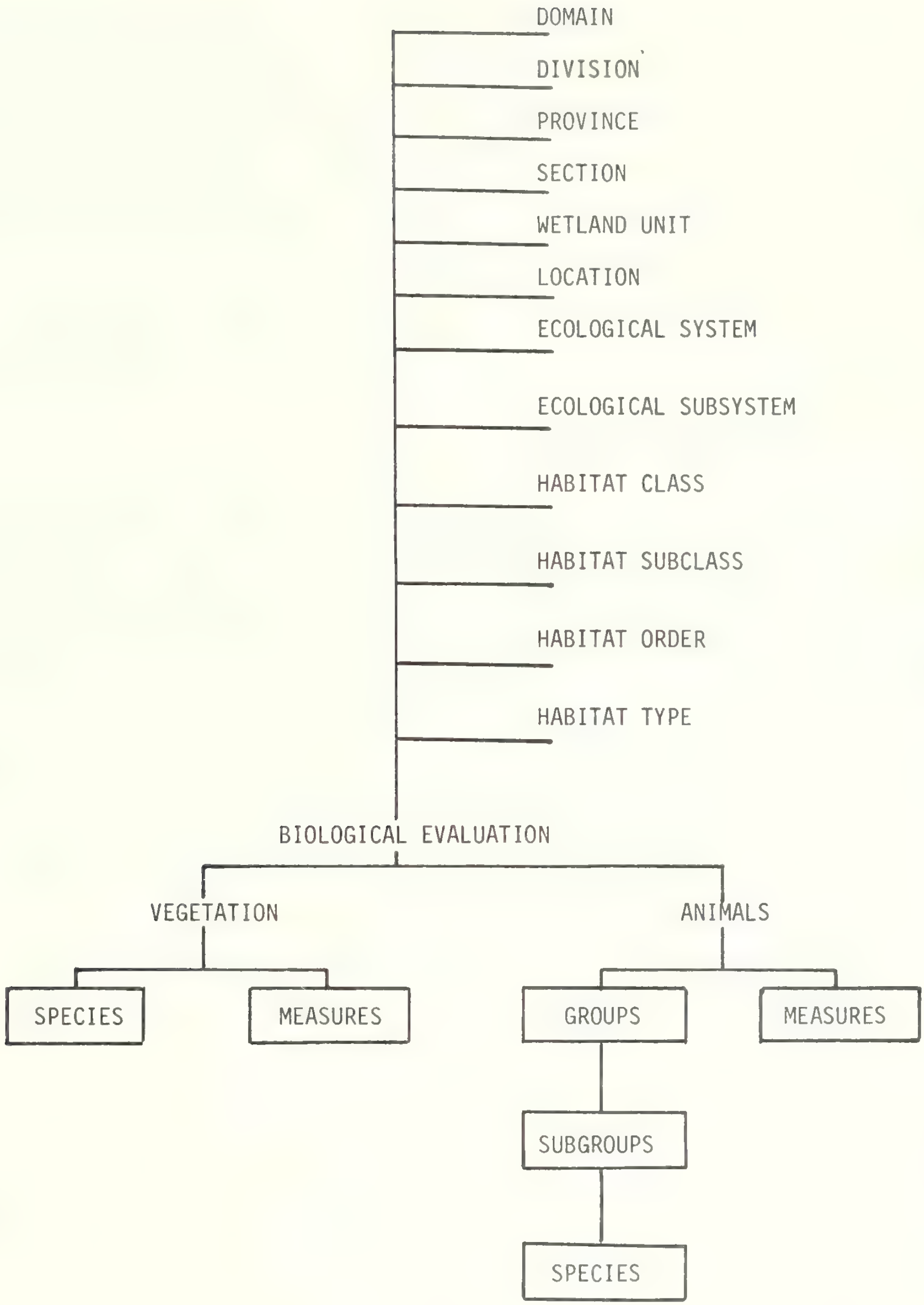


Figure 2. Biological organization - classification system relationship.

SOURCES OF DATA

A thorough search was conducted for data on the wetlands of Harney Basin. Major sources included the scientific literature, computer outputs on annual refuge inventories, annual reports, in-house reports, theses, the first-year reports from the Harney Basin studies by Ecological Services, and student projects from the field station. Data from over 50 references were used to test the system, although references were reviewed. The computer outputs provided the largest volume of data, making up over 75 percent of the approximately 4,000 entries. Most of these data dealt with waterfowl abundance and production. No effort was made to assess the validity of each reference; this should be the responsibility of the system's users.

In general, the Harney Basin had a reasonably extensive data base. However, the diversity of the data is low, reflecting the specialized interests of those groups who collected most of the data.

DESCRIPTION OF COMPUTERIZATION

After examining the types of data sources containing wetland information, BEAK personnel decided that a computerized method of compiling the data into a usable form was much more feasible than a manual method. The computerized method requires that the data be converted to a coding system, entered into the computer, processed, decoded, and printed. To accomplish this, data sheets were designed that could be easily filled out by the reviewer, easily keypunched, and designed so the data could be easily placed in a standard format without extensive programming.

Three different data sheet types were designed (Figures 3-5). Data sheet type 1 consists of three sections:

1. A section for a reference number and bibliographical citation.

2. A section for coding wetland type using USFWS wetland classification scheme.

3. A section to code pertinent animal information using the biological evaluation scheme.

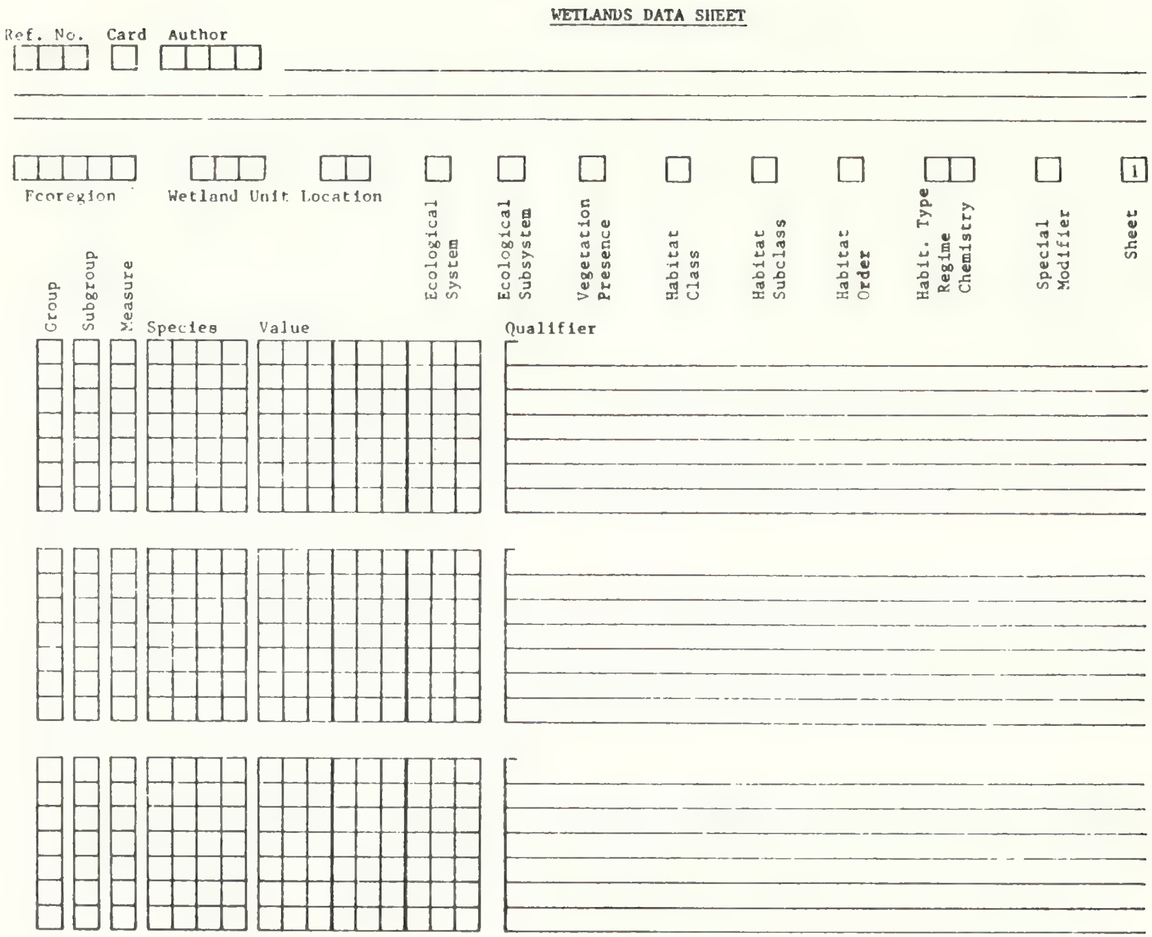
Data sheet type 2 contains two sections:

1. A section with a reference number and wetland type.

2. A section to code pertinent vegetation information.

Data sheet type 3 is used only when there are large lists of animal information and contains the same information that is on sheet 1, with the exception of the complete citation. This sheet was designed to eliminate extensive rewriting of information for each animal species.

Due to the complexity of interpreting and standardizing the data recording process we prepared a set of "Instructions to Reviewers" for future, similar efforts. These instructions were written to assist a biologist with no previous experience in reviewing pertinent wetland articles and extracting the appropriate data in a computer-ready format.



WETLANDS DATA SHEET

Ref. No. Card Author

Ecoregion Wetland Unit Location

Ecological System

Ecological Subsystem

Vegetation Presence

Habitat Class

Habitat Subclass

Habitat Order

Habit. Type Regime Chemistry

Special Modifier

Sheet 1

Group Subgroup Measure Species Value Qualifier

Figure 3. Wetlands data sheet number 1.

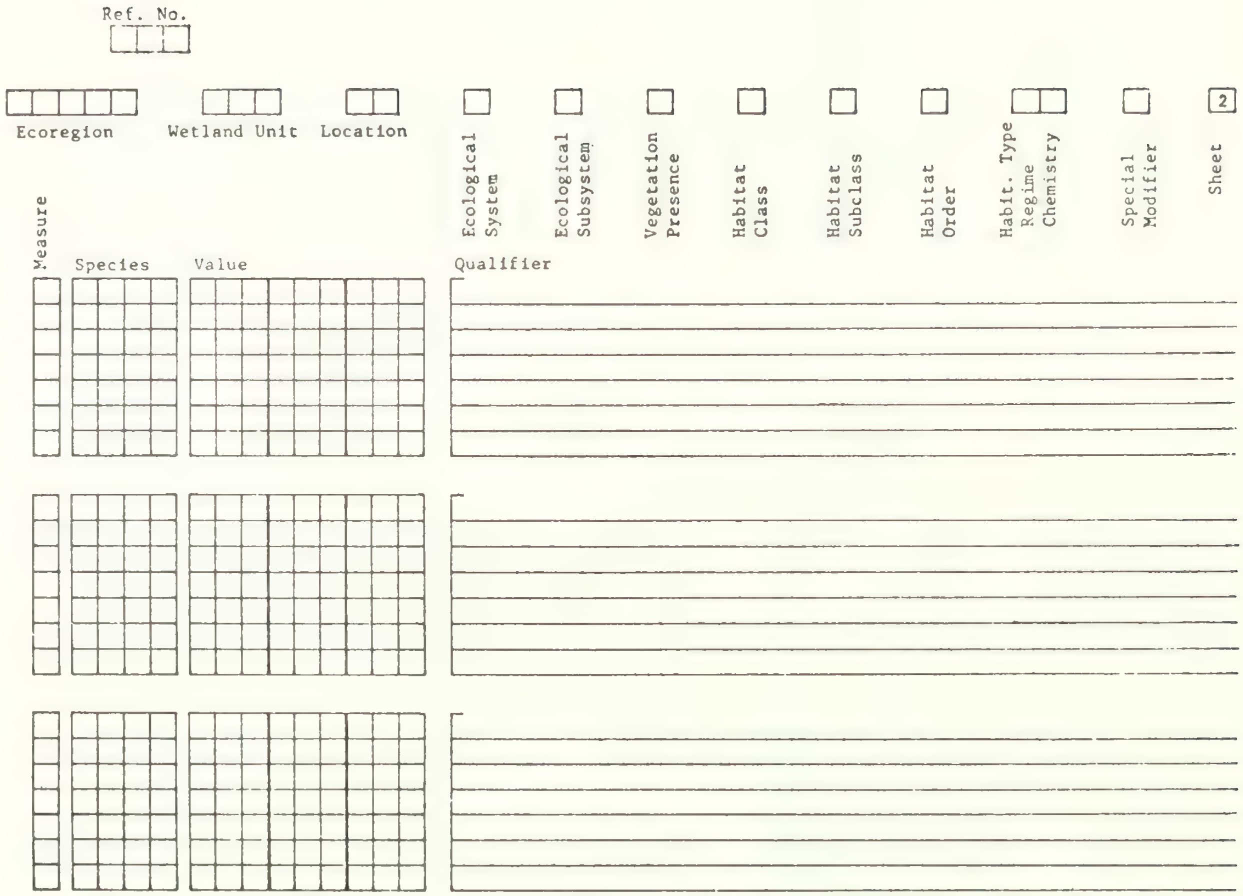
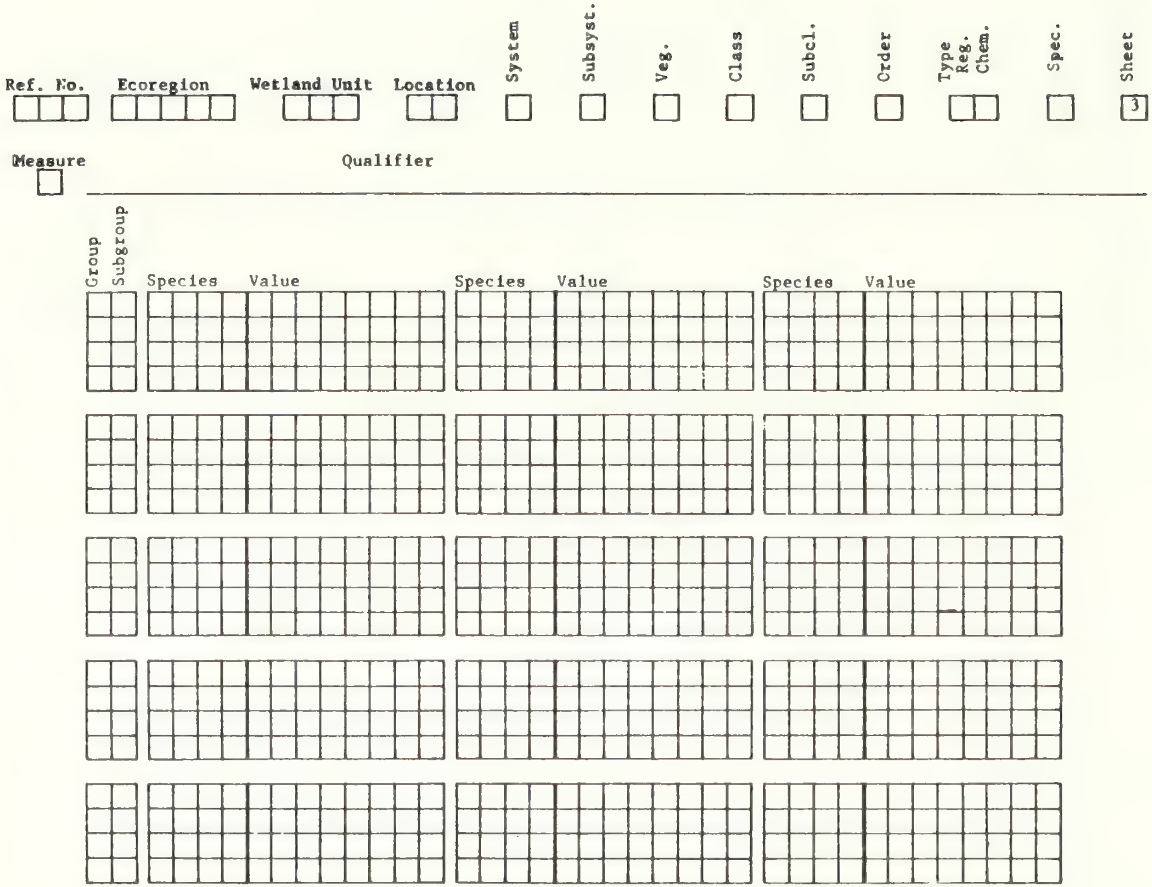


Figure 4. Wetlands data sheet number 2.



Ref. No. ☐☐☐ Ecoregion ☐☐☐☐☐ Wetland Unit ☐☐☐ Location ☐☐ System ☐ Subsyst. ☐ Veg. ☐ Class ☐ Subcl. ☐ Order ☐ Type Reg. Chem. ☐☐ Spec. ☐ Sheet 3

Measure ☐ Qualifier

Group Subgroup Species Value Species Value Species Value

Figure 5. Wetlands data sheet number 3.

A FORTRAN computer program was written to check for legal codes, assign each species code a sequence number, and to again place in format the data file so that it could be sorted in a logical manner. A second FORTRAN program was written to decode the sorted file and to produce the output. The flow diagram in Figure 6 contains a complete process description.

We found it desirable to return the initial output from the decoding program to a reviewer-supervisor familiar with the wetland being examined in order to check for obvious coding errors such as unusually large values, unexpected species, etc. Inconsistencies were checked against the reference. Then the input file was edited and a final report produced. We recommend that such an edit procedure be included in any subsequent wetland evaluation in order to assure a high-quality data base.

DATA OUTPUT

The format of the data output was designed to best display the hierarchical organization of the data base and also reflects how output might be presented in the ultimate functional system, although this will require further definition. Figures 7-13 show examples of the output sheets. Each page of the output lists the combination of categories to which the data apply. All known data for each set of conditions is given hierarchical order before the next combination is presented. For Harney Basin, almost all heading changes occur at the biological type and below. For example, in Figures 7, 8, and 9 data are given for whistling swans (Olor columbianus) where the measure is abundance, the subgroup is waterfowl, the group is birds and the biological type is animals. Most of the wetland classification categories were not specified in this case but the location, wetland unit, and ecoregion were stated or obviously inferred from the various sources. In Figure 9 the species changes phylogenetically, but all other categories remain the same. This pattern of changing species continues until Figure 10 when the measure changes from abundance to reproduction. At that point the species begin again at the swans and all other categories hold constant. This order is repeated until all measures for all species of waterfowl have been presented and the subgroup changes to upland game (Figure 11). This pattern of hierarchical listings of data was carried out on all relevant biological data found for Harney Basin.

The data for these combinations are presented under the value and qualifier headings. The value is the number and its units are listed under the qualifier. Following the units is the date the information represents and is presented by year and month (e.g., 72/01 means January 1972). At the far right of each line of data is the reference code which indicates the source for that line. This code is keyed to a full citation which we have included in the bibliography. Other examples are provided to show instances where ecological systems and habitat categories were specified (Figures 12 and 13).

SEARCH FOR A COMPUTER SYSTEM

A final objective of this project was to recommend a data management system that would be a useful tool in the development of a wetlands evaluation system. To do this we first had to establish the requirements and needs of the system. Secondly, we had to examine available systems and methods that could be used to meet these requirements. Finally, we had to select and evaluate the most appropriate system.

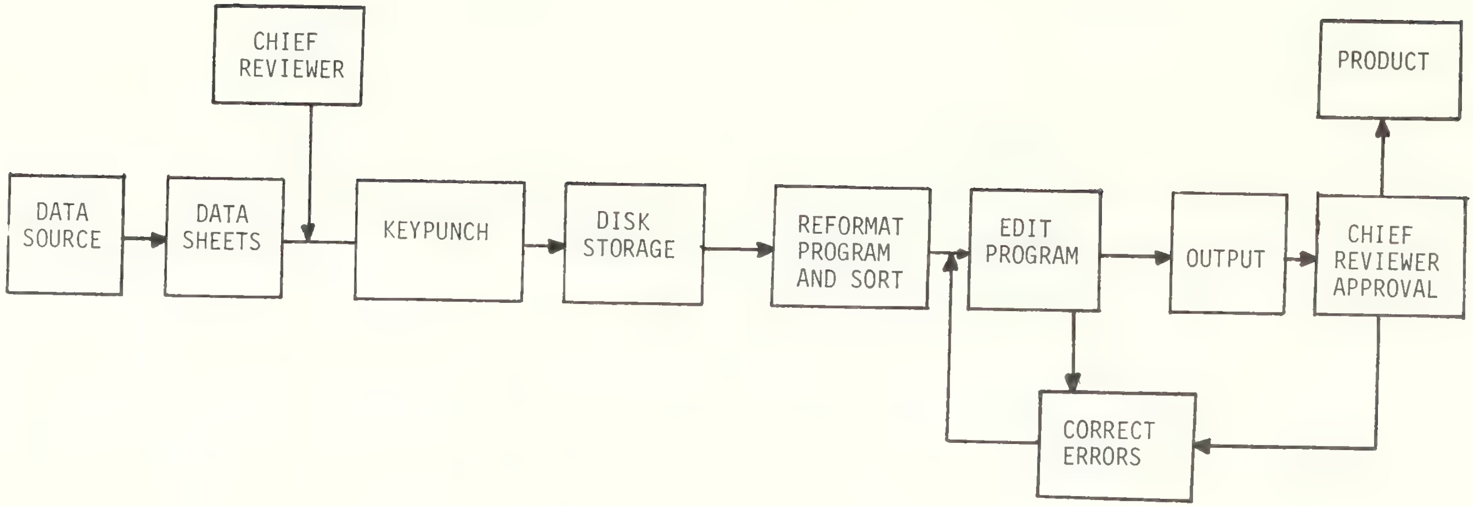


Figure 6. Flow diagram of data management process.

```
                                                      WETLANDS EVALUATION SYSTEM                                           PAGE:   1
DOMAIN:DRY     DIVISION: SEMI-ARID STEPPE     PROVINCE: INTER-MOUNTAIN SAGEBRUSH     SECTION: SAGEBRUSH-WHEATGRASS
  WETLAND UNIT: HARNEY BASIN    LOCATION: MALHEUR NATIONAL WILDLIFE REFUGE
   ECOLOGICAL SYSTEM:          NOT SPECIFIED
   ECOLOGICAL SUB-SYSTEM:      NOT SPECIFIED
   VEGETATION PRESENT:         NOT SPECIFIED
   CLASS:                      NOT SPECIFIED
   SUBCLASS:                   NOT SPECIFIED
   ORDER:                      NOT SPECIFIED
   WATER REGIME:               NOT SPECIFIED
   WATER CHEMISTRY:            NOT SPECIFIED
   HABITAT SPECIAL MODIFIERS:NOT SPECIFIED

    BIOLOGICAL TYPE: ANIMALS
     GROUP: BIRDS
     SUB-GROUP:

        **MEASURE: ABUNDANCE

         SPECIES NAME                                         VALUE                QUALIFIER                                    REF
          ALL SPECIES INDICATED ABOVE                          97900    TOTAL USE DAYS 72/01-72/03                               A01
                                                             2531130    TOTAL USE DAYS 72/04-72/06                               A01
                                                             5521420    TOTAL USE DAYS 72/07-72/09                               D03
                                                             5929130    TOTAL USE DAYS 72/07-73/06                               D03
                                                              407710    TOTAL USE DAYS 72/10-72/12                               D03
                                                              113280    TOTAL USE DAYS 73/01-73/03                               A12
                                                             5001720    TOTAL USE DAYS 73/04-73/06                               A12

     GROUP: BIRDS
     SUB-GROUP: WATERFOWL

        **MEASURE: ABUNDANCE

         SPECIES NAME                                         VALUE                QUALIFIER                                    REF
          WHISTLING SWAN (OLOR COLUMBIANUS)                       70    AVE. NO. 72/01                                           G01
                                                                 140    AVE. NO. 72/02                                           G01
                                                                2680    AVE. NO. 72/03                                           G01
                                                                  50    AVE. NO. 72/04                                           G01
                                                                1550    AVE. NO. 72/10                                           A08
                                                               13000    AVE. NO. 72/11                                           A08
                                                                2225    AVE. NO. 72/12                                           A08
                                                                  35    AVE. NO. 73/01                                           A09
                                                                4700    AVE. NO. 73/02                                           A09
                                                                7450    AVE. NO. 73/03                                           A09
                                                                 200    AVE. NO. 73/04                                           A09
                                                                  50    AVE. NO. 73/10                                           A07
                                                                1400    AVE. NO. 73/11                                           A07
                                                                  70    AVE. NO. 73/12                                           A07
                                                                  10    AVE. NO. 74/01                                           A02
                                                                2375    AVE. NO. 74/02                                           A02
                                                                2400    AVE. NO. 74/03                                           A02
------------------------
    CAUTIONARY NOTE:
   ENTRIES REFLECT THE LITERATURE; THE ACCURACY OF THE LITERATURE CANNOT BE GUARANTEED AND INTERPRETATION SHOULD BE
   ATTEMPTED ONLY BY QUALIFIED INDIVIDUALS. REFER TO THE TEXT BY BEAK CONSULTANTS, INC. (1976) FOR GENERAL EXPLANATION
```

Figure 7. Example of data output.

```
                                              WETLANDS EVALUATION SYSTEM                                          PAGE:   2

DOMAIN:DRY     DIVISION: SEMI-ARID STEPPE     PROVINCE: INTER-MOUNTAIN SAGEBRUSH     SECTION: SAGEBRUSH-WHEATGRASS
 WETLAND UNIT: HARNEY BASIN    LOCATION: MALHEUR NATIONAL WILDLIFE REFUGE
  ECOLOGICAL SYSTEM:          NOT SPECIFIED
  ECOLOGICAL SUB-SYSTEM:      NOT SPECIFIED
  VEGETATION PRESENT:         NOT SPECIFIED
  CLASS:                      NOT SPECIFIED
  SUBCLASS:                   NOT SPECIFIED
  ORDER:                      NOT SPECIFIED
  WATER REGIME:               NOT SPECIFIED
  WATER CHEMISTRY:            NOT SPECIFIED
  HABITAT SPECIAL MODIFIERS:NOT SPECIFIED

   BIOLOGICAL TYPE: ANIMALS
    GROUP: BIRDS
    SUB-GROUP: WATERFOWL

       **MEASURE: ABUNDANCE

        SPECIES NAME                                               VALUE              QUALIFIER                                  REF
         WHISTLING SWAN (OLOR COLUMBIANUS)                         (CONT.)
                                                                       25    AVE. NO. 74/04                                     A02
                                                                      165    AVE. NO. 74/10                                     G03
                                                                     2180    AVE. NO. 74/11                                     G03
                                                                      501    AVE. NO. 74/12                                     G03
                                                                      185    AVE. NO. 75/02                                     G03
                                                                    14000    AVE. NO. 75/03                                     G03
                                                                     2785    AVE. NO. 75/04                                     G03
                                                                       37    AVE. NO. 75/06                                     G03
                                                                       35    PEAK NO. 73/01                                     A11
                                                                    10000    PEAK NO. 73/02                                     A11
                                                                    14000    PEAK NO. 73/03                                     A11
                                                                      900    PEAK NO. 73/04                                     A11
                                                                      300    PEAK NO. 73/10                                     A11
                                                                     2700    PEAK NO. 73/11                                     A11
                                                                      100    PEAK NO. 73/12                                     A11
                                                                       10    PEAK NO. 74/01                                     D04
                                                                     4700    PEAK NO. 74/02                                     D04
                                                                     1600    PEAK NO. 74/02                                     D04
                                                                     4700    PEAK NO. 74/03                                     D04
                                                                      185    PEAK NO. 75/02                                     A03
                                                                    20900    PEAK NO. 75/03                                     A03
                                                                    10219    PEAK NO. 75/04                                     A03
                                                                     6300    USE DAYS 72/01-72/02                               G02
                                                                   591450    USE DAYS 72/01-72/12                               G02
                                                                    81900    USE DAYS 72/03-72/04                               G02
                                                                   503250    USE DAYS 72/09-72/12                               G02
                                                                   142050    USE DAYS 73/01-73/02                               A15
                                                                   229500    USE DAYS 73/03-73/04                               A15
                                                                    45600    USE DAYS 73/10-73/12                               A13
                                                                   229680    USE DAYS 74                                        A04
                                                                   143550    USE DAYS 74/01-74/03                               A04
                                                                      750    USE DAYS 74/04-74/06                               A04
-------------------------
    CAUTIONARY NOTE:
   ENTRIES REFLECT THE LITERATURE; THE ACCURACY OF THE LITERATURE CANNOT BE GUARANTEED AND INTERPRETATION SHOULD BE
   ATTEMPTED ONLY BY QUALIFIED INDIVIDUALS. REFER TO THE TEXT BY BEAK CONSULTANTS, INC. (1976) FOR GENERAL EXPLANATION
```

Figure 8. Example of data output.

```
                                                  WETLANDS EVALUATION SYSTEM                                             PAGE:   3

DOMAIN:DRY     DIVISION: SEMI-ARID STEPPE     PROVINCE: INTER-MOUNTAIN SAGEBRUSH     SECTION: SAGEBRUSH-WHEATGRASS
 WETLAND UNIT: HARNEY BASIN    LOCATION: MALHEUR NATIONAL WILDLIFE REFUGE
  ECOLOGICAL SYSTEM:          NOT SPECIFIED
  ECOLOGICAL SUB-SYSTEM:      NOT SPECIFIED
  VEGETATION PRESENT:         NOT SPECIFIED
  CLASS:                      NOT SPECIFIED
  SUBCLASS:                   NOT SPECIFIED
  ORDER:                      NOT SPECIFIED
  WATER REGIME:               NOT SPECIFIED
  WATER CHEMISTRY:            NOT SPECIFIED
  HABITAT SPECIAL MODIFIERS:NOT SPECIFIED

   BIOLOGICAL TYPE: ANIMALS
    GROUP: BIRDS
    SUB-GROUP: WATERFOWL

      **MEASURE: ABUNDANCE

       SPECIES NAME                                           VALUE              QUALIFIER                              REF
        WHISTLING SWAN (OLOR COLUMBIANUS)                     (CONT.)
                                                               85380    USE DAYS 74/10-74/12                            A04
                                                              425550    USE DAYS 75/01-75/03                            A05
                                                               83550    USE DAYS 75/04-75/06                            A05
        TRUMPETER SWAN (OLOR BUCCINATOR)                          90    AVE. NO. 72/01                                  G01
                                                                  45    AVE. NO. 72/02                                  G01
                                                                  45    AVE. NO. 72/03                                  G01
                                                                  40    AVE. NO. 72/04                                  G01
                                                                  40    AVE. NO. 72/05                                  G01
                                                                  40    AVE. NO. 72/06                                  G01
                                                                  40    AVE. NO. 72/07                                  A08
                                                                  45    AVE. NO. 72/08                                  A08
                                                                  45    AVE. NO. 72/09                                  A08
                                                                  45    AVE. NO. 72/10                                  A08
                                                                  45    AVE. NO. 72/11                                  A08
                                                                  45    AVE. NO. 72/12                                  A08
                                                                  45    AVE. NO. 73/02                                  A09
                                                                  50    AVE. NO. 73/04                                  A09
                                                                  50    AVE. NO. 73/05                                  A09
                                                                  40    AVE. NO. 73/06                                  A09
                                                                  50    AVE. NO. 73/07                                  A07
                                                                  45    AVE. NO. 73/09                                  A07
                                                                  45    AVE. NO. 73/10                                  A07
                                                                  45    AVE. NO. 73/11                                  A07
                                                                  40    AVE. NO. 73/12                                  A07
                                                                  35    AVE. NO. 74/01                                  A02
                                                                  40    AVE. NO. 74/02                                  A02
                                                                  40    AVE. NO. 74/03                                  A02
                                                                  40    AVE. NO. 74/04                                  A02
                                                                  35    AVE. NO. 74/05                                  A02
                                                                  35    AVE. NO. 74/06                                  A02
                                                                  35    AVE. NO. 74/07                                  G03
                                                                  40    AVE. NO. 74/08                                  G03
-------------------------
   CAUTIONARY NOTE:
  ENTRIES REFLECT THE LITERATURE; THE ACCURACY OF THE LITERATURE CANNOT BE GUARANTEED AND INTERPRETATION SHOULD BE
  ATTEMPTED ONLY BY QUALIFIED INDIVIDUALS. REFER TO THE TEXT BY BEAK CONSULTANTS, INC. (1976) FOR GENERAL EXPLANATION
```

Figure 9. Example of data output.

```
                                              WETLANDS EVALUATION SYSTEM                                                   PAGE:  59

DOMAIN:DRY     DIVISION: SEMI-ARID STEPPE     PROVINCE: INTER-MOUNTAIN SAGEBRUSH     SECTION: SAGEBRUSH-WHEATGRASS
  WETLAND UNIT: HARNEY BASIN    LOCATION: MALHEUR NATIONAL WILDLIFE REFUGE
   ECOLOGICAL SYSTEM:          NOT SPECIFIED
   ECOLOGICAL SUB-SYSTEM:      NOT SPECIFIED
   VEGETATION PRESENT:         NOT SPECIFIED
   CLASS:                      NOT SPECIFIED
   SUBCLASS:                   NOT SPECIFIED
   ORDER:                      NOT SPECIFIED
   WATER REGIME:               NOT SPECIFIED
   WATER CHEMISTRY:            NOT SPECIFIED
   HABITAT SPECIAL MODIFIERS:NOT SPECIFIED

    BIOLOGICAL TYPE: ANIMALS
     GROUP: BIRDS
     SUB-GROUP: WATERFOWL

       **MEASURE: ABUNDANCE

        SPECIES NAME                                             VALUE            QUALIFIER                                  REF
         AMERICAN COOT (FULICA AMERICANA)                        (CONT.)
                                                                   47250   USE DAYS 72/01-72/02                              G02
                                                                 9078300   USE DAYS 72/01-72/12                              G02
                                                                 3093600   USE DAYS 72/03-72/04                              G02
                                                                 3625500   USE DAYS 72/05-72/08                              G02
                                                                 2311950   USE DAYS 72/09-72/12                              G02
                                                                   88500   USE DAYS 73/01-73/02                              A15
                                                                 1857000   USE DAYS 73/03-73/04                              A15
                                                                 1470000   USE DAYS 73/05-73/08                              A15
                                                                  906000   USE DAYS 73/07-73/09                              A13
                                                                  513000   USE DAYS 73/10-73/12                              A13
                                                                 2798100   USE DAYS 74                                       A04
                                                                  268350   USE DAYS 74/01-74/03                              A04
                                                                  975000   USE DAYS 74/04-74/06                              A04
                                                                 1329300   USE DAYS 74/07-74/09                              A04
                                                                  225450   USE DAYS 74/10-74/12                              A04
                                                                  100800   USE DAYS 75/01-75/03                              A05
                                                                 1051050   USE DAYS 75/04-75/06                              A05
                                                                 1051050   USE DAYS 75/04-75/06                              A05


       **MEASURE: REPRODUCTION

        SPECIES NAME                                             VALUE            QUALIFIER                                  REF
         TRUMPETER SWAN (OLOR BUCCINATOR)                             10   BREEDING PAIRS 75                                 A46
                                                                       3   BROODS PRODUCED 75                                A46
                                                                      11   NO. PRODUCED 72/07-73/06                          D01
                                                                       6   NO. PRODUCED 73/07-74/06                          A14
                                                                       7   NO. PRODUCED 75                                   A46
                                                                      30   PERCENT NEST SUCCESS 75                           A46
                                                                      33   PERCENT REGION 1 PRODUCTION 74                    A30
         CANADA GOOSE (BRANTA CANADENSIS)                            724   BREEDING PAIRS 75                                 A46
                                                                     232   BROODS PRODUCED 75                                A46
-----------------------
    CAUTIONARY NOTE:
   ENTRIES REFLECT THE LITERATURE; THE ACCURACY OF THE LITERATURE CANNOT BE GUARANTEED AND INTERPRETATION SHOULD BE
   ATTEMPTED ONLY BY QUALIFIED INDIVIDUALS. REFER TO THE TEXT BY BEAK CONSULTANTS, INC. (1976) FOR GENERAL EXPLANATION
```

Figure 10. Example of data output.

```
                                        WETLANDS EVALUATION SYSTEM                                            PAGE:  63
DOMAIN:DRY     DIVISION: SEMI-ARID STEPPE     PROVINCE: INTER-MOUNTAIN SAGEBRUSH     SECTION: SAGEBRUSH-WHEATGRASS
 WETLAND UNIT: HARNEY BASIN    LOCATION: MALHEUR NATIONAL WILDLIFE REFUGE
  ECOLOGICAL SYSTEM:          NOT SPECIFIED
  ECOLOGICAL SUB-SYSTEM:      NOT SPECIFIED
  VEGETATION PRESENT:         NOT SPECIFIED
  CLASS:                      NOT SPECIFIED
  SUBCLASS:                   NOT SPECIFIED
  ORDER:                      NOT SPECIFIED
  WATER REGIME:               NOT SPECIFIED
  WATER CHEMISTRY:            NOT SPECIFIED
  HABITAT SPECIAL MODIFIERS:NOT SPECIFIED

   BIOLOGICAL TYPE: ANIMALS
    GROUP: BIRDS
    SUB-GROUP: WATERFOWL

       **MEASURE: COMMENTS

        SPECIES NAME                                       VALUE            QUALIFIER                         REF
         GADWALL (ANAS STREPERA)                             325   NO. HARVESTED 73/07-74/06                  A14
         PINTAIL (ANAS ACUTA)                                 70   NO. HARVESTED 73/07-74/06                  A14
         GREEN-WINGED TEAL (ANAS CRECCA CAROLINENSIS)         45   NO. HARVESTED 73/07-74/06                  A14
         AMERICAN WIGEON (ANAS AMERICANA)                    200   NO. HARVESTED 73/07-74/06                  A14
         NORTHERN SHOVELER (ANAS CLYPEATA)                   100   NO. HARVESTED 73/07-74/06                  A14
         WOOD DUCK (AIX SPONSA)                                5   NO. HARVESTED 73/07-74/06                  A14
         REDHEAD (AYTHYA AMERICANA)                            5   NO. HARVESTED 73/07-74/06                  A14
         BUFFLEHEAD (BUCEPHALA ALBEOLA)                       10   NO. HARVESTED 73/07-74/06                  A14
         WATERFOWL                                           928   NO. HARVESTED  73/07-74/06                 A14
         AMERICAN COOT (FULICA AMERICANA)                      5   NO. HARVESTED 73/07-74/06                  A14

    GROUP: BIRDS
    SUB-GROUP: UPLAND GAME

       **MEASURE: ABUNDANCE

        SPECIES NAME                                       VALUE            QUALIFIER                         REF
         SAGE GROUSE (CENTROCERCUS UROPHASIANUS)             100   PEAK NO. 73/07-74/06                       A16
                                                           17800   USE DAYS 73/07-74/06                       A16
         VALLEY QUAIL (LOPHORTYX CALIFORNICUS)              1000   PEAK NO. 73/07-74/06                       A16
                                                          246200   USE DAYS 73/07-74/06                       A16
         RING-NECKED PHEASANT (PHASIANUS COLCHICUS)         2000   PEAK NO. 73/07-74/06                       A16
                                                          420000   USE DAYS 73/07-74/06                       A16
         CHUKAR (ALECTORIS CHUKAR)                           150   PEAK NO. 73/07-74/06                       A16
                                                           12800   USE DAYS 73/07-74/06                       A16
         MOURNING DOVE (ZENAIDA MACROURA)                    400   PEAK NO. 73/07-74/06                       A16

       **MEASURE: REPRODUCTION

        SPECIES NAME                                       VALUE            QUALIFIER                         REF
-----------------------
    CAUTIONARY NOTE:
   ENTRIES REFLECT THE LITERATURE; THE ACCURACY OF THE LITERATURE CANNOT BE GUARANTEED AND INTERPRETATION SHOULD BE
   ATTEMPTED ONLY BY QUALIFIED INDIVIDUALS. REFER TO THE TEXT BY BEAK CONSULTANTS, INC. (1976) FOR GENERAL EXPLANATION
```

Figure 11. Example of data output.

```
                                        WETLANDS EVALUATION SYSTEM                                           PAGE: 154

DOMAIN:DRY     DIVISION: SEMI-ARID STEPPE     PROVINCE: INTER-MOUNTAIN SAGEBRUSH     SECTION: SAGEBRUSH-WHEATGRASS
  WETLAND UNIT: HARNEY BASIN    LOCATION: MANAGEMENT UNIT 5, MALHEUR NATIONAL WILDLIFE REFUGE
   ECOLOGICAL SYSTEM:          PALUSTRINE
   ECOLOGICAL SUB-SYSTEM:      NOT SPECIFIED
   VEGETATION PRESENT:         YES
   CLASS:                      EMERGENT WETLAND
   SUBCLASS:                   VASCULAR
   ORDER:                      NOT SPECIFIED
   WATER REGIME:               SEMI-PERMANENTLY FLOODED
   WATER CHEMISTRY:            NOT SPECIFIED
   HABITAT SPECIAL MODIFIERS:NOT SPECIFIED

    BIOLOGICAL TYPE: ANIMALS
     GROUP: BIRDS
     SUB-GROUP: WATERFOWL

        **MEASURE: REPRODUCTION

         SPECIES NAME                                        VALUE            QUALIFIER                          REF
          MALLARD (ANAS PLATYRHYNCHOS)                           5    BREED. PR. OBSV., 640A BLOCK, 66           H01
                                                                 2    BROODS OBSV., 640A BLOCK, 66               H01
          GADWALL (ANAS STREPERA)                                5    BREED. PR. OBSV., 640A BLOCK, 66           H01
                                                                 1    BROODS OBSV., 640A BLOCK, 66               H01
          CINNAMON TEAL (ANAS CYANOPTERA)                        2    BREED. PR. OBSV., 640A BLOCK, 66           H01
          AMERICAN WIGEON (ANAS AMERICANA)                       1    BREED. PR. OBSV., 640A BLOCK, 66           H01
          REDHEAD (AYTHYA AMERICANA)                            16    BREED. PR. OBSV., 640A BLOCK, 66           H01
                                                                 2    BROODS OBSV., 640A BLOCK, 66               H01
          CANVASBACK (AYTHYA VALISINERIA)                        1    BREED. PR. OBSV., 640A BLOCK, 66           H01
          LESSER SCAUP (AYTHYA AFFINIS)                          1    BREED. PR. OBSV., 640A BLOCK, 66           H01
          RUDDY DUCK (OXYURA JAMAICENSIS)                       16    BREED. PR. OBSV., 640A BLOCK, 66           H01
          DUCKS                                                 11    % BREED. SUCCESS, 640A BLOCK, 66           H01
                                                                47    BREED. PR. OBSV., 640A BLOCK, 66           H01
                                                                 5    BROOD. OBSV., 640A BLOCK, 66               H01


        **MEASURE: COMMENTS

         SPECIES NAME                                        VALUE            QUALIFIER                          REF
          MALLARD (ANAS PLATYRHYNCHOS)                                MOLTING AREA                               H01
          PINTAIL (ANAS ACUTA)                                        MAJOR MOLTING AREA                         H01
          AMERICAN WIGEON (ANAS AMERICANA)                            MOLTING AREA                               H01


     GROUP: BIRDS
     SUB-GROUP: OTHERS

        **MEASURE: COMMON SPECIES LIST

         SPECIES NAME                                        VALUE            QUALIFIER                          REF
          HORNED GREBE (PODICEPS AURITUS)                        2    OBSV., 640A BLOCK, 66/06                   H01
          EARED GREBE (PODICEPS NIGRICOLLIS)                  1140    OBSV., 640A BLOCK, 66/06                   H01
------------------------
     CAUTIONARY NOTE:
    ENTRIES REFLECT THE LITERATURE; THE ACCURACY OF THE LITERATURE CANNOT BE GUARANTEED AND INTERPRETATION SHOULD BE
    ATTEMPTED ONLY BY QUALIFIED INDIVIDUALS. REFER TO THE TEXT BY BEAK CONSULTANTS, INC. (1976) FOR GENERAL EXPLANATION
```

Figure 12. Example of data output.

```
                                        WETLANDS EVALUATION SYSTEM                                                      PAGE: 156

DOMAIN:DRY     DIVISION: SEMI-ARID STEPPE     PROVINCE: INTER-MOUNTAIN SAGEBRUSH     SECTION: SAGEBRUSH-WHEATGRASS
  WETLAND UNIT: HARNEY BASIN     LOCATION: MANAGEMENT UNIT 5, MALHEUR NATIONAL WILDLIFE REFUGE
   ECOLOGICAL SYSTEM:          PALUSTRINE
   ECOLOGICAL SUB-SYSTEM:      NOT SPECIFIED
   VEGETATION PRESENT:         YES
   CLASS:                      EMERGENT WETLAND
   SUBCLASS:                   VASCULAR
   ORDER:                      NOT SPECIFIED
   WATER REGIME:               SEMI-PERMANENTLY FLOODED
   WATER CHEMISTRY:            NOT SPECIFIED
   HABITAT SPECIAL MODIFIERS:NOT SPECIFIED

    BIOLOGICAL TYPE: VEGETATION

       **MEASURE: MAJOR SPECIES

        SPECIES NAME                                          VALUE             QUALIFIER                          REF
         WATER MILFOIL (MYRIOPHYLLUM EXALBESCENS)                                                                  H01
         BALTIC RUSH (JUNCUS BALTICUS)                                                                             H01
         SINGLESTEM BURRFED (SPARANGIUM EMERSUM)                                                                   H01
         BROAD-LEAVED CATTAIL (TYPHA LATIFOLIA)                                                                    H01


       **MEASURE: RARE OR ENDANGERED SPECIES

        SPECIES NAME                                          VALUE             QUALIFIER                          REF
         CHARA SPP.                                               5   % OCCURRENCE IN SAMPLE OPEN WATER H.T. 66/08  H01


       **MEASURE: COMMENTS

        SPECIES NAME                                          VALUE             QUALIFIER                          REF
         ALL SPECIES INDICATED ABOVE                           53.9   % OF 640A BLOCK THAT IS EMERGENT H.T. 66/08   H01
                                                               46.1   % OF 640A BLOCK THAT IS OPEN WATER H.T. 66/08 H01
                                                                345   A EMERGENT H.T. IN 640A BLOCK 66/08           H01
                                                                295   A OPEN WATER H.T. 66/08                       H01
                                                                 65   % OCCURRENCE INS SAMPLE, OPEN WATER H.T. 66/08 H01
          WATER MILFOIL (MYRIOPHYLLUM EXALBESCENS)               98   % OCCURRENCE IN SAMPLE, EMERGENT H.T. 66/08   H01
          HARDSTEM BULRUSH (SCIRPUS ACUTUS)                           DOMINANT SPP.                                 H01
                                                                  5   % OCCURRENCE IN SAMPLE, OPEN WATER H.T. 66/08 H01
          SAGO PONDWEED (POTAMOGETON PECTINATUS)                      ABUNDANT IN NE                                H01
                                                                 20   % OCCURRENCE IN SAMPLE, OPEN WATER H.T. 66/08 H01
          SMALL PONDWEED (POTAMOGETON PUSILLUS)                   2   % OCCURRENCE IN SAMPLE, EMERGENT H.T. 66/08   H01
          BROAD-LEAVED CATTAIL (TYPHA LATIFOLIA)                  5   % OCCURRENCE IN SAMPLE, OPEN WATER H.T. 66/08 H01
          HORNED PONDWEED (ZANNICHELLIA PALUSTRIS)



------------------------
   CAUTIONARY NOTE:
  ENTRIES REFLECT THE LITERATURE; THE ACCURACY OF THE LITERATURE CANNOT BE GUARANTEED AND INTERPRETATION SHOULD BE
  ATTEMPTED ONLY BY QUALIFIED INDIVIDUALS. REFER TO THE TEXT BY BEAK CONSULTANTS, INC. (1976) FOR GENERAL EXPLANATION
```

Figure 13. Example of data output.

Time constraints prevent a full description of the efforts expended toward this objective. Briefly, we found no system capable of meeting all the data management needs of an evaluation system. However, the review did indicate that System 2000 of MRI Systems Corporation best fulfills the initial requirements of the wetland evaluation system. As the evaluation system is further developed, and its uses and capabilities better defined, System 2000 will provide the basis for designing the system which the U.S. Fish and Wildlife Service may eventually implement.

BIBLIOGRAPHY

Bella, D.A. and P.C. Klingeman. 1973. General Planning Methodology for Oregon's Estuarine Natural Resources. Oregon State Univ. Corvallis. 113 pp.

Bureau of Sport Fisheries and Wildlife. 1971. Program Planning - Budgeting - Evaluation System Handbook WRH-5. Bur. Sprt Fish. and Wildl., Washington, D.C.

Bureau of Sport Fisheries and Wildlife. 1972. Program Planning - Budgeting - Evaluation System Handbook WRH-4. Bur. Sport Fish. and Wildl., Washington, D.C.

Copeland, B.J. 1970. Estuarine classification and responses to disturbances. Trans. Am. Fish. Soc. 99:826-834.

Cowardin, L.M., and U.C. Carter. 1975. Tentative Classification for Wetlands of the United States. U.S. Fish and Wildl. Serv., Wetland Inventory, Preliminary Rep. 43 pp.

Cowardin, L.M., and P.H. Johnson. 1973. A Preliminary Classification of Wetland Plant Communities in North-Central Minnesota. Special Sci. Rep. - Wildl. 168:U.S. Bur. Sport Fish. and Wildl., Washington, D.C. 33 pp.

DeBates, L.W. 1967. The role of small wetland preservation in comprehensive prairie pothole region planning. Trans. North Am. Wildl. Conf. 32:325-331.

Geis, J.W., R.P. Curran, and J.R. Roman. 1974. Adirondack wetland evaluation: one approach to a complex regional problem, pp. 7-18 In W.G. Berberet (ed.), Proc. Northern New York - Lake Champlain Environ., Miner Center, Chazy, New York.

Golet, F.C. 1973. Classification and Evaluation of Freshwater Wetlands as Wildlife Habitat in the Glaciated Northeast. Bur. Sport. Fish. and Wildl., Resource Publication 116, Washington, D.C. 56 pp.

Gupta, T.R., and J.H. Foster. 1975. Economic criteria for freshwater wetland policy in Massachusetts. Am. J. Agric. Econ.:40-45.

National Academy of Sciences, National Academy of Engineering. 1971. Jamaica Bay and Kennedy Airport, A Multidisciplinary Environmental Study. Natl. Acad. Sci., Natl. Acad. Engin., Washington, D.C., Vol. I, 27 pp.; Vol. II, 149 pp.

New York Department of Environmental Conservation. 1972. Long Island Marine Wetlands. New York Dept. Environ. Conserv., Albany. 60 pp.

O'Connor, J.S., and O.W. Terry. 1972. The Marine Wetlands of Nassau and Suffolk Counties. Marine Sci. Res. Cent., State Univ. New York, Stony Brook. 99 pp.

Pacific Northwest River Basins Commission. .1970. Water Resources, Columbia - North Pacific Region Comprehensive Framework Study. Pacific Northwest River Basins Comm. Appendix V. 536 pp.

Rose, B.J., and H.R. Morgan. 1964. A priority rating system for Canadian wetlands preservation. Trans. North Am. Wildl. Conf. 29:248-258.

Sanderson, G.C., and F.C. Bellrose. 1969. Wildlife habitat management of wetlands. An Acad. Brasil. Ciēnc. Suplemento 41:153-204.

Seher, J.S., and P.T. Tueller. 1973. Color aerial photos for marshland. Photogrammetric Engin. 1973:489-499.

Shaw, S.P., and C.G. Fredine. 1956. Wetlands of the United States. U.S. Dept. Interior, Circ. 39. 67 pp.

Smardon, R.C. 1973. Visual-cultural values of wetlands. In Larson, J.S. (ed.), A Guide to Important Characteristics and Values of Freshwater Wetlands in the Northeast. Water Resour. Res. Cent., Univ. Massachusetts at Amherst. Publ. 31:9-11 pp.

Stephen, W.J.D. 1969. Research Requirements for the Establishment of Wetland Preservation Objectives. Canadian Wildl. Serv., Edmonton, Alberta. 19 pp.

Stewart, R.E., and H.A. Kantrud. 1972. Vegetation of Prairie Potholes, North Dakota, in Relation to Quality of Water and Other Environment Factors. Geological Survey Professional Paper 585-D. U.S. Govt. Printing Office. 36 pp.

Wilsey and Ham, Inc. 1974. Estuarine Resources of the Oregon Coast. Wilsey and Ham, Inc., Portland, Oregon. 233 pp.

ENVIRONMENTAL VALUE MAPPING:[1] AN INDISPENSABLE TOOL OR TRAP?

Carlos M. Fetterolf, Jr., Executive Secretary
Great Lakes Fishery Commission
1451 Green Road
Ann Arbor, Michigan 48105

Abstract: The International Joint Commission, charged with assisting the governments in the implementation of the 1972 Canada-U.S. Great Lakes Water Quality Agreement, has formulated water quality objectives to protect the most sensitive uses made of Great Lakes waters. However, there are several categories of areas exempted from compliance. Such areas represent a loss of biological value to the ecosystem, often making achievement of desired management goals impossible.

A well-defined international-interstate mechanism for limiting present and future losses of value is necessary, both locally and on a water body basis. A mechanism is suggested which involves agreement on management objectives, identification of habitat, establishment of value according to function and proportional quantity of supporting habitat, and allocation or rehabilitation of habitat so that adequate function can take place and management objectives can be achieved.

A water body atlas (environmental maps) displaying the system in a holistic manner with emphasis on habitat function would be extremely valuable in developing any water body management scheme. Participants in a workshop to investigate the potential and feasibility of developing such maps were strongly against the concept of assigning numerical values to various habitats, and the allocation of value to uses which could result in interference with biological integrity of the water body. The participants supported environmental mapping of water bodies for agency use in decision making and for use by laymen to further develop a supportive constituency.

I will tell a story that goes a step beyond the classification, inventory, and analysis of habitat and suggests using such information in matching management objectives with habitat by placing a numerical value on the biological and sociological function of habitat. The value would be based in part on the quantity of habitat with similar function in the water body. The mechanism, which involves allocation of value to present and future users, could be used either to maintain the present biological integrity of the water body, to restore former biological communities and uses, or to limit further losses, depending on management objectives. However, there's a major problem with the mechanism: several people in high places don't like it. In the words of one, it's a "sugar coated arsenic pill."

The Great Lakes are a priceless resource. They comprise 80 percent of the North American freshwater reservoir, stretch 800 miles (1,287 Km) west to east, 500 miles (804 Km) north to south, and have 5,000 miles (8,045 Km) of shoreline. Forty-five million people call the basin home. There is an annual 6 billion dollar tourist and recreation industry including, in part, the 450 million dollar sport and commercial fishery. The connecting channels make up the busiest commercial shipping lanes in the world. The Great Lakes surface area is 93,000 square miles (149,637 Km^2)--32 percent Canadian, 68 percent American--but that is just the beginning of dividing the pie. To the north the Province of Ontario has regulatory authority for fisheries and environmental quality, on the U.S. side there are eight states with such regulatory authority. Thus, Lake Erie has five masters, lakes Michigan and Superior four each, and lakes Huron and Ontario two each. There are innumerable governmental entities and programs involved with the resources of the lakes. All of these forces have their own philosophies, strategies and dictums, some complementary, some not.

---

[1] Another way of saying classification, inventory and analysis of habitat. This paper chronicles the experiences of the author while working on an International Joint Commission Subcommittee and workshop. The ideas and opinions do not reflect those of the Great Lakes Fishery Commission.

The governments of Canada and the U.S. have provided two tools to promote resource management, cohesiveness, and coordination of activity on a water body basis, the International Joint Commission (IJC) that deals with water levels and water quality issues, and the international Great Lakes Fishery Commission whose mission is to control sea lamprey and determine the research and management necessary to improve and perpetuate the fishery resources. Neither commission has regulatory authority, but they provide the fora in which unification of purpose and programs takes place.

Signing of the Canada-U.S. Great Lakes Water Quality Agreement in 1972 was a shot in the arm to the venerable IJC and has resulted in a burst of activity towards reaching the plateau from which attaining the lofty goals of the Water Quality Agreement (IJC 1972) should be possible. Yet, there are questions whether a true integrity, a true wholeness, the reaching of desired management objectives, can be achieved on a water body basis when a limiting mechanism is missing and some vague definitions remain.

In 1973-74 I chaired the IJC Water Quality Objectives Subcommittee which, working in conjunction with the standing Committee on Scientific Basis for Water Quality Criteria from IJC's Research Advisory Board, developed specific water quality objectives for the Great Lakes. The Agreement provides this definition, "Specific water quality objective means the level of a substance, or physical (or biological) effect, that the Parties agree, after investigation, to recognize as a maximum or minimum desired limit for a defined body of water or portion thereof, taking into account the beneficial uses of the water which the Parties desire to secure and protect." Following tradition, we derived objectives (IJC 1975) that describe a minimum quality of water which, by protecting the most sensitive use, will provide for any specific use of the water.

The Subcommittee members and their scientific consultants were mostly biologists, toxicologists, and environmental chemists. We were reluctant to turn our recommendations over to administrative decisionmakers without guidance on how, where, and when our mostly numerical objectives should be used. We developed a conceptual framework replete with caveats within which water quality objectives could be used appropriately (IJC 1975). We pointed out that in its present form the Agreement restricts mixing zones to the "vicinity" of outfalls, urges keeping localized areas of noncompliance to a "minimum," and establishes a nondegradation philosophy of taking "reasonable and practicable measures" to maintain water quality where it is better than the prescribed objectives. We stated that we did not believe these unquantifiable terms provided an adequate framework to prevent excessive areas of the Great Lakes from remaining in noncompliance with objectives or, in the future, to prevent excessive areas from being degraded to the objectives.

Our emphasis was on areas not in compliance with water quality objectives. By definition, water quality objectives describe minimum acceptable conditions. If those conditions are not met, there is a loss of value. We were reluctant to provide specific water quality objectives when no well-defined international-interstate mechanism existed for limiting areas of noncompliance or, said another way, for limiting the present and future losses of value, not only locally, but on a water body basis.

There are three basic elements of the Water Quality Agreement: water quality objectives, surveillance, and remedial programs. There are several categories of noncompliance with objectives: whole lake problems such as persistent contaminant residues in fish; areas out of compliance because of natural causes; and "problem areas, localized areas of noncompliance" such as harbors in urban areas not likely to be cleaned up for a long time because of urban runoff, channelization, dredging and filling, shoreline modification, etc. Wherever anthropogenic noncompliance occurs, there has been a tradeoff. There can be only so many trade-offs before you discover that the ecosystem community and uses which were your management objectives have really not been traded off, they have been ripped off, nickeled and dimed to death.

The function of biologically valuable areas, essential to ecosystem stability in lakes, has been lost. Spawning areas in rivers have been made inaccessible by dams or pollution. We lost Atlantic salmon (Salmo salar) and many adfluvial genetic strains of other species. Protected areas which were important nurseries for valuable fish species are now called harbors, "localized areas of noncompliance." It is obvious to even the casual observer that there is a limit to these losses before ecosystem imbalance and ultimate collapse of populations occur. We lost the blue pike (Stizostedion vitreum glaucum), a close relative of the yellow walleye (Stizostedion vitreum vitreum). An academic argument goes on whether the fish is extinct or not, but only 26 years ago, in 1949, Lake Erie produced 23,783,000 pounds (Baldwin and Saalfeld 1962). Where did they spawn? What was their habitat? Nobody is certain but we think the profundal of Lake Erie played a part. In late summer 1973, the anoxic (dissolved oxygen < 1 mg/l) region comprised 94 percent of the hypolimnion and 70 percent of the central basin (IJC 1976a). Too bad nobody described the habitat requirements of blue pike and mapped those habitats before we lost them.

One of the Subcommittee's key concerns was mixing zones, areas where noncompliance with water quality objectives or standards is allowed. Mixing zones are often arbitrarily limited in size and configuration to simplify enforcement and accommodate treatment capability. We should have better sense. They should be limited in size, configuration, and number on the basis of interference with uses and management objectives. Yes, handle mixing zones on a case-by-case basis, ...but never forget that the receiving system, the water body, is a case too. How do you handle future mixing zones unless you have a water body map showing all the previous cases your agency and others have handled on a case-by-case basis?

We suggested to IJC that if the management objective is multi-purpose use of a Great Lake, including the most sensitive uses, the key to maintaining or achieving high-value sensitive uses is rehabilitation or protection of those parts of the ecosystem that contribute most importantly to production of those uses. Provide or protect the habitat so the function can take place.

Being a narrow-minded bunch of scientists, we developed and suggested a limiting mechanism based entirely on biologically important habitat and function. It was similar to the water body mixing zone limitation plan in an early draft (U.S. EPA 1974) of the U.S. Environmental Protection Agency guidelines for thermal discharges (Section 316a of PL 92-500), which was dropped from the final guidelines.

Basic precepts include:

1. All areas of noncompliance with water quality objectives in the water body, or segment thereof, must be included.

2. The acceptable area of loss is related to the functional value of the habitat and the amount of equivalent habitat.

3. Areas supporting "critical functions" should be inviolate.

4. Acceptable losses and the level of protection should be related to resiliency of system.

5. Think in terms of potential value of habitat, not just the existing value of degraded habitat.

Simplified, the basic steps of the strictly biologically based limiting mechanism are:

1. Agree on management objectives. Presently it is a hopeless case if entity A wants one fish community and B, who shares the same water body, wants another.

2. Identify important species and their reproductive and survival strategies. What is an important species? Those important in sports or commercial fishing, in the food chain producing those creatures, or in maintenance of system structure and function.

3. Establish their seasonal biotic zones.

4. Assign numerical value to zones by units of area on basis of importance to ecosystem function. Value would be higher if habitat is in short supply, and lower if there are huge areas.

5. Select a level of protection. This is where social choice comes in, because the greater the level of protection desired, the greater will be the restrictions against further encroachment, or the greater the need for rehabilitation. This is the step where we all get impressed once again that there is no free lunch.

6. Calculate value of areas already not in compliance and those that are available for uses not in compliance with water quality objectives. This is where you may find you have some value to trade off while still maintaining your ability to achieve your management objectives, or you find you cannot trade any more. Or you find you have already lost too much, to the point that water body integrity in line with management objectives is threatened, or already down the drain. At that point you have two choices: downgrade your management objective, or rehabilitate some of the critical habitat you have already lost.

7. Allocate value to present noncompliance uses while maintaining a reserve for the future. This is when the bartering gets really complicated between those entities sharing the water body, and it is discovered that entity A has already used more than their share and entity B has lots of value left to use. I would like to be at the bargaining table, but not have them know whose committee suggested the plan.

A factor is missing from the above scheme because of our narrow-mindedness. Other sites such as beaches, parks, water intakes, and aesthetic areas must be added to those habitats receiving very high numerical values/unit or those considered inviolate. The Committee, therefore, changed the name from biological value allocation to environmental value allocation.

To summarize, the mechanism amounts to limiting areas of noncompliance so you can achieve your management objectives. It involves allocation of value losses,and takes into account past, present, and future areas of noncompliance. Encroachment on those parts of the system (habitats) which contribute most importantly to production of sensitive uses is limited proportionately by quantity of that habitat type.

The IJC listened to the Subcommittee and said, in effect, "Develop this further." The U.S. and Canadian cochairman of the IJC's Water Quality Board stated, "The Subcommittee has caused us to rethink some of the basic elements of the Water Quality Agreement" (personal communication, Francis T. Mayo and James P. Bruce to author, 1975). We basked in the sunshine briefly. But conceiving is more fun than giving birth.

We recognized that a water body map displaying environmental values was essential to any allocation scheme. This would obviously involve classification and quantification of habitat plus identification of its quality, function, and productivity, not only in its present condition and with the existing fish community but of its potential, given better environmental quality and a better "engineered" fish species mix.

In May 1976, the IJC's Research Advisory Board approved holding a workshop on Environmental Value Mapping. The Water Quality Board's 1975 Annual Report stated, "The Water Quality Board awaits the product of the workshop, for the Board feels it is necessary to have a water body value map to reach any defensible decision on water body management. The Board is considering promoting the development of water body value maps for each Great Lake as an interagency project coordinated by IJC as an accompaniment to any water body management scheme" (IJC 1976b). Recently, some Board members are expressing disbelief and surprise that their report said that. I could not believe it either, because the rumblings of discontent had started months earlier--who is going to place the numerical values on the habitats? Who can do this in light of changing social values? We will be locked into a giveaway system. There should be no mixing zones, zero discharge. Maps I drew up 20 years ago of important environmental areas have been reproduced year after year for decision-making today by mining exploration engineers, sand and gravel companies, gas well drillers, and other exploiters. We do not know enough of ecosystem structure and function to dare produce maps; we would be kidding ourselves and our constituents. There will be blank spaces on the maps; what is their value? The maps will be misused. Any writeoff is fatal for fisheries. Every smidgen of that habitat is high value. Our management strategy is restoration and rehabilitation, not giveaway. Those irretrievable values we have already lost constitute our trade-off. You are asking us to select the least harmful site, it is a fait accompli. The U.S. may have policies in place to hold the line, but in Canada this would be used to degrade and exhaust our resources further. Multiple use equals multiple destruction. Environmental matters are of such low priority it is inconceivable to think of them having a high priority.

We held the workshop in November 1976. The planning was excruciating because we really did not know just what we wanted to know and neither did our invited speakers. We scheduled six major sessions, over 3 days, to address or do the following:

1. Relative to potential users of maps, what would you, as a coastal zone manager, as a fisheries manager, as one planning for catastrophe contingencies, as one who dredges and fills, as an industrialist, as a water supply engineer, as a promoter of ecosystem understanding, and so on--what would you like to see on environmental value maps? Let yourself go, we will come back to reality later.

2. Relative to previous mapping efforts, why did you do it? What did you map? What did you not map? Why? What would you do differently if you had it to do over again? How much did it cost? How long did it take? Is it used? Would you do it again?

3. Have an open debate at an evening session.

4. Discuss availability of information.

5. Have concurrent group sessions summarize and identify priorities.

6. Make conclusions, recommendations, and determine research needs.

Did we ever get an earful! Many of the preworkshop rumblings came from the first invited speaker, and the debate was on. There was much emotion on two issues, "value" being one. To make progress and clear the air the steering committee announced a ban against uttering and publishing the word "value." The second issue was allocation. Since the allocation mechanism was not on the program except in my introductory address, it was not mentioned again. With "value" and "allocation" out of the way, there was considerable support for environmental mapping.

The Subcommittee has said repeatedly that we are not convinced that the value-allocation limiting mechanism we proposed is a panacea, or even that we advocated its adoption. Our objective is to have an international-interstate limiting mechanism in place on the Great Lakes. By proposing one, we are forcing thought on the need for some limiting mechanism to mesh with management objectives. We hope to keep the pressure on, while watching the horizon for the cavalry. We don't see any bright young faces with ideas, or any old grizzly ones with firepower, coming to the rescue.

A political scientist at the workshop mentioned something which fits in with an earlier presentation made at this symposium. Control of information is power. There is an aura of mystery surrounding the decisions made by regulatory agencies. Is information which could go on environmental maps jealously guarded within regulatory agencies as a bolster to authority, an internal power booster?

Several workshop speakers commented that recent experience has shown that dissemination of environmental information builds a constituency in the public.

This point is reemphasized in the following portion of the draft workshop summary for which I was responsible (IJC 1977).

"Previous major environmental mapping efforts on Chesapeake Bay, the New York Bight, the Gulf of Mexico, and the rivers of Great Britain, as well as several minor specialty efforts in other areas, were reviewed in light of the following questions: what has been mapped; why were the maps developed; were the efforts worthwhile; and what approach should be followed if a Great Lakes environmental mapping effort is mounted.

WHAT HAS BEEN MAPPED?

"Depending on purpose, the maps displayed, in varying degree, the fundamental characteristics of the system, processes, and man's uses of the resource. Specific subjects for maps included: distribution of commercially and recreationally important species and effort to harvest; habitat and topography (both shoreline and benthic); function of habitat; physical, chemical, and biological qualities and processes; shoreline processes; cultural development and activities; hydrological and energy processes; and trends in the environment.

WHY WERE THE MAPS DEVELOPED?

"The compelling reason for developing environmental maps was to display simultaneously two or more concurrent or related situations so that alternatives and implications could be perceived by managers. The developers of the maps soon realized that their efforts could be used to address matters in dispute. At that point, mapping took two directions: internal for technical purposes, external for public purposes.

"Environmental maps for external purposes usually address those issues of importance to the public or issues that planners and managers wish to bring to public attention. If issues are important to the public, they are important politically and, because the political process is vital to the welfare of management and regulatory agencies, there is a closed circle of interdependence. Public issues addressed by the environmental maps discussed during the workshop included: aesthetic fouling of beaches; swimming water quality; beach and shoreline erosion; storm surges and river flooding; fishless rivers; grossly polluted water; contaminated fish and shellfish; recreational opportunities and access; availability of fish and fishing; overcrowding and conflicting uses; protection of habitat; industrial and cultural development; and overall planning.

"Environmental maps for internal use included a wider variety of parameters in greater detail than those prepared for the public. The system can be revealed in a holistic manner, with emphasis on function leading to better understanding among interdisciplinary sciences and decisionmakers. Such understanding should result in cooperative decisions complementary to overall management objectives.

"Besides being a tool in decisionmaking, other internal agency uses involve:

1. identifying concurrent or conflicting water uses,

2. selecting management objectives,

3. preparing environmental impact statements leading to impact minimization,

4. designing research and surveillance,

5. understanding of trends through time,

6. identifying habitat which must be protected, preserved or restored, and

7. future planning.

"A very simple quote from one participant sums up the purpose of environmental maps: 'So mankind can avoid gross errors.'

WERE THE EFFORTS WORTHWHILE?

"The displays were used extensively when any internal decisions involving the water body were being made by management agencies. The displays themselves served as the basis of debate and influenced acceptance or rejection of ideas.

"The displays prepared for external use, those that address public issues, were extremely valuable to the welfare of the resource and the responsible agencies. The displays raised the environmental consciousness of the public. Maps were a solution to the problem of explaining environmental concepts and the issues at hand to laymen and scientists alike. Maps facilitated the transmission of factual information, communicated the interrelationships of factors in the system, and linked environmental science to the personal interests and concerns of the public.

"Caring is something one acquires through exposure and understanding. A sense of belonging is not legislated or commanded, it seeps into your being as one becomes a part of things. Environmental maps have created an understanding and a sense of caring in the public. A feeling that 'this is my resource,' 'my lake,' 'my bay' has been developed. Historical environmental maps, compared with those of today, show the public what they have lost compared with what they have today, and what they could have in the future. Such displays can build a constituency for a water body, a public which speaks for their resource.

WHAT APPROACH SHOULD BE FOLLOWED IF A GREAT LAKES ENVIRONMENTAL MAPPING EFFORT IS MOUNTED?

"Guidelines which the discussants agreed upon include:

1. Clearly define the purpose of the exercise before selecting the issues to be addressed and the parameters to be included.

2. Emphasize basics that explain the system and the fundamental relationships among cultural, physical, chemical, and biological characteristics.

3. Choose a pilot water body which is approachable and for which desired data are available.

4. Compile and display data in hand, rather than collecting new information.

5. Prepare historical and contemporary displays concurrently.

6. Time the project so that all segments are released simultaneously, not piecemeal.

7. Assign responsibility to a small team of highly qualified professionals, which includes an excellent, imaginative artist-cartographer.

8. The text accompanying the displays is of equal importance to the maps, a dynamic atlas to be updated as new information becomes available.

9. Caveats on currency of information, interpretation of data, and explanation of what is not known should be expressed clearly to guard against misuse of maps.

10. Commitment to the project must be expressed by the highest administrator of the resource agencies surrounding the water body to be mapped, because the project staff will need every agency's full cooperation."

In conclusion, I respect the "value allocation" concerns and opinions of my peers. One critic has suggested that far more discussion of the rehabilitation vs. zonation-allocation question should take place before committing the Great Lakes Fishery Commission and its cooperators to such a hazardous course. It is impossible for me to do that committing and the Commission has not considered the question. The Commissioners recommend policy and can encourage or discourage research and management direction, but only our cooperators themselves can commit. Response from fishery interests to the stimulus of "value allocation" has been predominantly noncommittal or negative, but there are islands of interest. My point is that an interstate-international limiting mechanism is not in place, that we continue to lose habitat, and that further work to promote a plan for protection and rehabilitation of habitat is necessary. I cannot afford the irresponsibility of leading in the controversial direction of "value allocation." A Judas goat is a leader, but not my type to imitate.

"Value allocation" aside, there is considerable scientific support within a variety of agencies for environmental mapping of the Great Lakes. The recommendations from the workshop to the IJC Research Advisory Board will encourage such an effort. I believe as yet unrecognized benefits will come from environmental mapping. This symposium devoted 3-1/2 days to hearing the problems involved. They can all be overcome. I believe that if Nat Reed, immediate past Assistant Secretary of Interior for Fish and Wildlife and Parks, who was also a Great Lakes Fishery Commission Commissioner, was here, he would say something akin to, but not as strong as, his concluding words at the 1976 National Symposium on PCB's where we heard for 3 days about all the problems with limiting PCB production, "Quite frankly, I am thoroughly disgusted by the gnashing of teeth, wailing, and rubbing of hands. ---GET ON WITH IT!" (Reed 1976).

POSTSCRIPT

On 20 October 1977, The Great Lakes Fishery Commission met with the International Joint Commission to discuss improvement of consultative and working mechanisms among the Commissions and their cooperators to accelerate the rate of progress towards attainment of improved ecosystem quality in the Great Lakes.

The Great Lakes Fishery Commission presented the following statement endorsing the concept of environmental mapping and emphasizing the importance of providing an historical perspective in addition to the current situation.

"This Commission endorses the concept of environmental mapping of the Great Lakes, and supports the Research Advisory Board's recommendation that cost/benefits, potentials and liabilities be determined through the effort expended on mapping a sub-area of the Great Lakes.

"It is our understanding that the Research Advisory Board has approved formation of a task force to develop a plan of study which will include recommendations on how the environmental mapping should be implemented. The task force will apparently examine alternatives and select a pilot study are on the basis of capability of producing a useful product, within available resources and in a reasonable period of time, for application to an important issue.

"We wish to point out that fishery interests will be very uncomfortable with an environmental map depicting the Great Lakes resources as they stand today, unless that map is accompanied by a map or series of maps showing the resources as they were in the past. Environmental maps of today's resources depict major losses but, without means of comparison, today's map may be interpreted as the baseline from which to measure future gains or losses. The baseline for those measurements should be historical and we hope the task force will examine this point and make a recommendation as to what time periods should be represented for comparison or baseline purposes. For different resources and different localities the intervals of the sequence should fit the situation but, generally speaking, fishery resources should be shown at frequent intervals through time.

"Until recently we would have said that depicting the fishery resource and its habitat at least in pre-sea lamprey-invasion days was necessary. However, in 1976 we funded a research project on historical aspects of 'Fish community transformation in three bays within the lower Great Lakes' by T. H. Whillans, a student working under the Direction of Dr. Henry Regier, University of Toronto. Mr. Whillans developed environmental maps of the bays which clearly implicate man's activities as factors negatively affecting fish habitat as long ago as 150 years. The point being that to improve our understanding of today's Great Lakes ecosystem and to provide assistance in today's resource management decisions, we must provide an historical perspective probably going back more than 40 years in some cases.

"The Great Lakes Fishery Commission is committed to rehabilitation of Great Lakes fishery resources and feels that today's resource manager and the public should know what has been lost in order to know what might be regained through rehabilitative initiatives. It would be an injustice to the resource, today's resource manager, and the public if only today's snapshot was used to depict an environmental situation which must be viewed as part of a time series.

"We urge you make our feelings known to the Research Advisory Board's Task Force on Environmental Mapping."

LITERATURE CITED

Baldwin, N.S. and R.W. Saalfeld. 1962. Commercial Fish Production in the Great Lakes, 1867-1960. Great Lakes Fishery Commission, 1451 Green Road, Ann Arbor, Michigan. 166 pp.

International Joint Commission. 1972. Agreement between the United States of America and Canada on Great Lakes Water Quality. 69 pp.

International Joint Commission. 1975. Great Lakes Water Quality 1974. Appendix A, Annual Rep. of the Water Quality Objectives Subcommittee. 239 pp.

International Joint Commission. 1976a. Great Lakes Water Quality 1975. Appendix B, Ann. Rep. Surveillance Subcommittee. 255 pp.

International Joint Commission. 1976b. Great Lakes Water Quality 1975. Ann. Rep. 162 pp.

International Joint Commission. 1977. Workshop on Environmental Mapping of the Great Lakes. 224 pp.

Reed, N.P. 1976. U.S. Federal agency roles and actions: the Department of the Interior, pp. 434-437 in Proceedings of the National Conference on Polychlorinated Biphenyls (EPA-560/6-75-004). Office of Toxic Substances, Environ. Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 1974. Draft 316(a) Technical Guidance - Thermal Discharges. Water Planning Div., Office of Water and Hazardous Materials, Environ. Protection Agency, Washington, D.C.

HIGHWAYS AND WILDLIFE: IMPLICATIONS FOR MANAGEMENT

Daniel L. Leedy, Research Director
Urban Wildlife Research Center, Inc.
12789 Folly Quarter Road
Ellicott City, Maryland 21043

Abstract: The author was principal investigator of a Federal Highway Administration project in 1975 which resulted in the publication, by that agency's Offices of Research and Development, of Reports FHWA-RD-76-4 and FHWA-RD-76-5 entitled Highway-Wildlife Relationships: Volume 1, a state-of-the-art report, and Volume 2, an annotated bibliography. The combined reports summarized much of the published information and current research efforts on this subject. The present paper extracts information from these earlier reports and addresses, in relation to fish and wildlife conservation and management, both detrimental and beneficial effects of highway construction, maintenance, and use, as well as opportunities for mitigating damage to the habitat and for enhancing wildlife values.

The 20 million or more acres (8,092,000 ha) in highway rights-of-way have been largely neglected as wildlife habitat; yet, at least a part of the edge habitat along the nearly 4 million miles (6,436,000 km) of the Nation's highways and streets provide usable habitat for birds, small mammals, and other wildlife. Although many impoundments created through highway construction have been beneficial to fish and wildlife and recreation, the values could have been increased markedly through planning and input of sound biological information and know-how. Similarly, habitat damage already caused by highway construction, maintenance, and use could be reduced by application of mitigation measures such as rehabilitation of channelized streams, more effective erosion and pollution control, and improved roadside vegetation management. The wildlife values of plants used for roadside plantings should be given consideration along with erosion control and aesthetic values.

Many millions of wild vertebrates are killed annually on streets and highways, but, apparently, most wildlife populations are not seriously affected by such losses. Use of fencing, highway underpasses, and other measures have reduced the incidence of losses of human life and property resulting from deer and other big game-vehicular accidents, but the need for more effective measures still exists. In parks and other areas, the opportunity for observation of big game animals and other wildlife, close to highways, by tourists and recreationists should not be overlooked.

Presumably most of our highway system has been completed and future highway construction will be in the form of widening or repairing existing highways. In highway reconstruction or in the development of new highways, as in Alaska, every consideration should be given to threatened or endangered species. It may be as important to know where not to build a highway, from the standpoint of biology and conservation, as it is to know where to build a highway from an engineering standpoint.

This paper is based largely upon a project conducted in 1975 by the Urban Wildlife Research Center for the Federal Highway Administration, Offices of Research and Development, Washington, D.C. This project involved a review of the literature dealing with highway-wildlife relationships and an appraisal of current research and research needs related to this subject. The project resulted in the publication of a state-of-the-art report and an annotated bibliography of 794 references. These publications are available as Reports FHWA-RD-76-4 and FHWA-RD-76-5 from the Federal Highway Administration or the National Technical Information Service, Springfield, Virginia, 22161. I wish to express appreciation for the FHWA support and to the U.S. Fish and Wildlife Service and other sponsors of this national symposium for the opportunity of presenting to you information from these two reports, and some additional material slanted toward the principal thrusts of this meeting.

The Urban Wildlife Research Center is a recently established private, nonprofit organization. In addition to the traditional views of fish and wildlife habitat, we recognize as habitat some built-up and developed areas which often are disregarded or neglected as such habitat. One of our objectives is to conduct research in urban or other developed areas and present the findings in a form that will be used by planners and developers. As a result, we hope that fish and wildlife environmental values will be enhanced and both wildlife and man will have a better place in which to live. In our work with highways and roads, we have been concerned not only with urban and suburban areas, but with roads in the countryside, and even with logging roads.

In the context of this session of the current symposium, I wish to: (1) indicate the extent of highways, roads, and streets in the United States; (2) discuss highways and highway rights-of-way as wildlife habitat; (3) mention some of the ecological relationships between highways--including their construction, maintenance, and use--and fish and wildlife; (4) outline some of the efforts being made to reduce or rectify detrimental effects of highways on fish and wildlife and their habitats; (5) review some of the limited efforts that have been made to manage highway rights-of-way to enhance fish and wildlife; and (6) suggest other opportunities for fish and wildlife management and research.

EXTENT OF HIGHWAYS AND STREETS

Exact information is not available on the amount of land occupied by surfaced roads and streets and the amount of land in highway rights-of-way that may be at least partially vegetated. Based upon a 1936-1937 investigation, Miller and Powell (1942) estimated that public highways occupied nearly 18 million acres (7,282,800 ha), or 0.7 percent of the total land area of the United States, excluding Alaska and Hawaii. They concluded, in connection with their survey of game and wild fur animal production, that on about three-quarters of the highway area it was economically feasible to improve food and cover for wildlife. Looking back some 40 years later, however, it would appear that little deliberate effort has been made to improve such lands for wildlife. Some seven years after Miller and Powell's study, Van Dersal (1943) calculated that 20,000,000 acres (8,092,000 ha) of the total land area were in highways and roads, and 4,000,000 acres (1,618,400 ha) were in railroad rights-of-way. During the period 1945-1954, the area occupied by highways increased about 78,000 acres (31,558 ha) per year (Wooten and Anderson, 1958). A program of inter-regional highways was authorized by Congress in 1956, which, as pointed out by Mayer (1958), provided for 41,000 miles (65,969 km) of modern highways, a substantial part of which would be in metropolitan areas with rights-of-way 250-300 feet (76.2-91.4 m) wide. Mayer suggested that at the interchanges between expressways and other arteries, vast areas of land would be made available for other development. In discussing this same program, Jordan (1968) stated that the superroads were gobbling up 1.6 million acres (657,360 ha) for rights-of-way--an area larger than the State of Delaware.

The Council on Environmental Quality (1974) reported that each mile of interstate highway consumes up to 48 acres (19.4 ha); over two-thirds of the land area in some cities is consumed by streets, roads and parking; and 26 million acres (10,519,600 ha) of America's rural land is consumed by the transportation system. Egler, in Egler and Foote (1975), stated that he had estimated, in about 1960, that the soil- and vegetation-covered lands in rights-of-way for highways, railroad, and utility lines embraced 50 million acres (20,230,000 ha) for the contiguous United States.

From these estimates we can assume that highway rights-of-way occupy over 20 million acres (8,092,000 ha) of land and water--an area certainly large enough to deserve more attention than currently with respect to fish and wildlife. As of 31 December 1973, the U.S. Department of Transportation (1973) reported the total mileage of highways and streets to be 3,806,883 (6,125,275 km) of which 3,175,654 miles (5,109,627 km) were classified as rural roads, and 631,229 (1,015,647 km) as municipal mileage. Presumably these totals do not include estimates, mileage-wise or acreage-wise, of logging roads and navigable trails in many timber or back-country areas, nor the road building done recently in Alaska in connection with the Alaska Pipeline. Discussions I heard at a September 1975 research conference sponsored by the Federal Highway Administration in Minneapolis, however, would indicate that the rate of construction of new highways has reached a a peak. Henceforth, it appears the emphasis will be on widening and improving existing highways, which may have the effect of reducing the amount of vegetated right-of-way along these highways.

HIGHWAYS AND HIGHWAY RIGHTS-OF-WAY AS WILDLIFE HABITAT

Many people, including some wildlife biologists, are inclined to write off the land encompassed in the highway system as a total loss to wildlife. They decry the loss or deterioration of habitat, they mention pollution effects on fish and wildlife, and they point out that millions of animals are killed annually on the nation's highways. They remind us, also, that vehicle collisions with deer and other animals may result not only in the loss of the animals, but in substantial property damage and the loss of some human lives as well. These charges are true, but there is another side to the coin. Let us look at both sides and consider some of the features, both beneficial and detrimental to fish and wildlife, that characterize the highway system. Many references not cited here can be located in the two volume highway-wildlife work mentioned previously (Leedy, 1975, Leedy et al, 1975). What I have to say will not be very profound. The fact is that little sophisticated or systematic research on highway-wildlife relationships has been done. It is hoped that research now being done or planned by the U.S. Fish and Wildlife Service and the Urban Wildlife Research Center, with support from the Federal Highway Administration, may provide more adequate analyses of highway rights-of-way as wildlife habitat. If hopes are realized, also, some of the principles or characteristics of the highway system, discussed here with respect to fish and wildlife, will be helpful or serve as reminders in future highway habitat analyses.

THE EDGE EFFECT

It is well known that the transition zone or ecotone between two types of plant communities, woods borders, and other edges is much used by wildlife. Roads create edges of one kind or another--nearly 4 million miles (6,436,000 km) of them (not counting both sides of the road), for, even in cities, many of the streets have trees between the pavement and the adjacent lawns or buildings. Not all highway rights-of-way provide good cover. Typically, however, there is a grassy strip, usually kept mowed, outside the road shoulders which grades into brush or other higher cover. In the case of divided highways, there is another strip of varying width, again plantings of shrubs and trees or native trees that were left standing during highway construction.

The grass-covered area may not be particularly valuable for wildlife, but depending upon the mowing regime, it provides a feeding area for birds such as starlings (Sturnus vulgaris), robins (Turdus migratorius), and small seed eaters, and it provides habitat for small mammals such as insectivores and rodents. Sometimes, the grass or other cover in highway rights-of-way that cut through large densely wooded areas, is attractive to deer. This attraction may lead to accidents if the deer get onto the highway.

Farther from the highway, in that portion of the right-of-way which is not kept closely mowed, there is likely to be excellent wildlife cover. Pheasant (Phasianus colchicus) nesting studies in Nebraska, for example (Linder, et al, 1960), and South Dakota (Trautman 1960) and studies of waterfowl in North Dakota (Oetting and Cassel, 1971; Stewart and Kantrud, 1973), showed relatively high densities of nests of these birds in roadside cover. As pointed out by Graham (1947), anyone who has traveled the broad highways of Texas scarcely can fail to notice the number of birds' nests in the trees and shrubs that have been planted there, especially in the prairies and other treeless sections where woody cover is scarce. Highways cut through timbered areas obviously result in the loss of trees and habitat for those bird species of the inner woods. This may result in reduction of birds such as red-eyed vireos (Vireo olivaceus) and some woodpeckers. However, as indicated by Michael et al (1976), when a road is constructed through a forest, two new habitat types are created--the seeded right-of-way and the edge area of herbaceous plants and shrubs that grow up between the grass and the forest. In their study of changes in bird populations that occurred along a section of newly constructed Highway 48 through Coopers Rock State Forest in West Virginia, these authors found significant increases in the number of starlings, and apparent increases in song sparrows (Melospiza melodia), indigo buntings (Passerina cyanea), white-throated sparrows (Zonotrichia albicollis), killdeer (Charadrius vociferus), and crows (Corvus brachyrhynchos), i.e., in the grassland or edge species.

With mammals, as in the case of birds, highway construction has destroyed habitat for some species and created habitat for others. For example, Baker (1971) observed that although farming, ranching, and suburbanization have encroached on the habitat of meadowmice and cottonrats (Sigmodon sp) encouragement of grasses along highway and railroad rights-of-way have opened up new territory to these grass-eaters.

CHANGES IN LAND FORMS AND DRAINAGE

The cuts and fills associated with highway construction alter habitat also, and again, the changes may be favorable to some species and detrimental to others. Cuts through mountainous or hilly areas, to attain an acceptable grade for a highway, may result in rocky cliff faces suitable for the nesting of certain birds; fills may result in the creation of wetlands or impoundments.

The adaptable starling has been observed feeding young in cavities formed by highway construction (Michael et al., 1971), and I have observed bank swallows (*Riparia riparia*) nesting in roadside cuts. Presumably some of the tunnels created in the course of highway construction are occupied by bats and other cave-dwelling species.

The impoundments formed by highway construction--all too often without consideration of fish and wildlife--may provide water or wetland areas valuable to fish and wildlife; and the roadside ditches created for drainage may be well populated by frogs, waterfowl, and other species, when they contain water.

In the course of road construction, considerable alteration of drainage is effected. An inventory of 768 miles (1,246 km) of stream channel along 13 Montana streams indicated there had been 1,987 individual alterations; highway construction ranked next to agriculture and railroad construction as a cause for the alteration. As a result of man-made alterations, channels were shortened by 68 miles (109.4 km) and standing crops of game fish were several times less abundant than in natural, meandering channels (Peters and Alvord, 1964).

Harmon (1971), in discussing highway drainage, stated: "New highway construction in the prairies (the pothole area of the Dakotas, western Minnesota and parts of Manitoba, Saskatchewan and Alberta) threatens vast numbers of wetlands. Less obvious than ditches dug solely for drainage, these projects can place drainage outlets within easy reach of most landowners. Federal funds go to both county and state highway departments to help expand the road system. Along with the money come certain engineering specifications conducive to increased drainage." He went on to say, ". . . a single road construction project, six miles in length, is now in the process of eliminating waterfowl habitat that produced more than 2,000 ducks per year."

A task force of the U.S. Department of Interior (1975) produced a report to provide information on effects of road construction on wetland wildlife management. Although the recommendations of the task force are not to be construed as representing approval or disapproval by the Secretary of the Interior or by the Director of the Fish and Wildlife Service, the findings indicated that in 19 western Minnesota counties an estimated 99,292 acres (40,173 ha) of wetland had been drained as a result of highway construction. On the 28,953 miles (46,585 km) of highway sampled, this drained area was at the rates of 2.33, 2.62 and 4.10 acres (0.9, 1.0 and 1.6 ha) respectively per mile of State and Federal, county, and township highway. Apparently, builders of locally financed township and county roads which were not a part of the Federal and state highway system have successfully circumvented environmental safeguards of the National Environmental Policy Act (NEPA) and the Department of Transportation Act.

HIGHWAYS: THEIR USE BY, AND EFFECTS ON, WILDLIFE

It may seem incongruous, but the highway itself serves as a part of the habitat of many wildlife species. One indication of this is the impressive highway mortality sustained annually by numerous wildlife species. The mortality results not only from movement of the animals from one side of the road to the other, but from the presence of animals such as ravens (*Corvus corax* and *C. cryptoleucus*) and crows feeding on other animals already killed, on earthworms, or on scattered grain or other tidbits left on the highway as a result of its use by man.

Grit needed by pheasants and many other birds is available from gravel roads and from the shoulders of paved roads. Some dirt or sandy rural roads provide a place for dust bathing by birds.

In Idaho, Dalke et al (1960) observed that in at least one situation, the road itself was used by sage grouse (*centrocerous urophasianus*) as a strutting (display and mating) area.

In Texas, Lehmann (1968) observed that in times of flood, the relatively rare Attwater prairie chicken (*Tympanuchus cupido*) was found concentrated on elevated roads out of reach of flood waters, but at the same time, subjected to hazards of automotive traffic.

Highway bridges, culverts, and other structures provide habitat for some species of wildlife. Most travelers using automobiles must have observed the presence of pigeons (*Columba livia*) near or under bridges where they very commonly nest and roost. Barn swallows (*Hirundo rustica*) and cliff swallows (*Petrochelidon pyrrhonota*) also nest under bridges (Denton, 1967 and Wallace, 1970). Martin (1974) indicated that at one time the cave swallow *Petrochelidon furlva*) was considered to be potentially endangered because, in Texas, it was thought to be restricted to sink holes and caves for breeding. Recently, however, Martin stated that the cave swallow has been found nesting in culverts. The problem is that culverts are used, also, by barn swallows and cliff swallows, a situation which he thinks may be hazardous to the species involved because of increased competition, vulnerability to disease or parasitism, and breakdown of reproductive isolating mechanisms.

Culverts may have a serious impact on fish. If not properly designed to allow fish passage, they can act as barriers to suitable spawning or feeding areas (Dryden and Jessop, 1974, U.S. Department of Agriculture, 1974).

In the case of the exotic or introduced starling, Miller (1975) observed that the automobile age had proved a boon. In addition to roadside feeding areas, he stated that the elevated expressways, overpasses, roadway ramps, and bridges now provide drier shelter and more ample perching space than the birds had in Victorian times. According to Miller (1975), starlings in New York have been discovered in a square mile of intersecting traffic arteries over the Harlem River, an area with fewer humans afoot than any other within miles of the city. The roosting of birds under some bridges results in guano deposits sufficient to be a problem in bridge painting and maintenance.

Davis and Cockrum (1963) stated that most bridges apparently provide sufficient shelter for night-roosting of bats, but in Arizona they found only two types of bridges with sheltered openings suitable for day-roosting of bats. They indicated that, with the trend toward the use of metal longitudinal undersupports, most newer bridges are not suitably constructed to serve as day-roosts. Bridges may serve another use with respect to mammals. Broadbrooks (1958) suggested that for many years the northward extension of the Kangaroo rat (*Dipodomys ordi*) apparently was blocked by the Columbia and Snake Rivers. He speculated that this animal may have succeeded in crossing these rivers via bridges, but recognized there were other possibilities also.

In desert or dry areas, hard-surfaced highways may result in sufficient runoff and increase in soil moisture in the highway berms to provide conditions suitable for the extension of the range of mammals such as the pocket gopher (Huey, 1941).

Practically everyone who has traveled on the nation's streets and highways has observed animals killed by automotive vehicles. The observed numbers killed annually are large indeed, and many animals that die after being struck by a vehicle move away from the road and hence are not seen by the travelers. Counts of highway animal victims have been made by biologists and others for years and numerous reports on such counts have been published. In a review of the literature on this subject (Leedy, et al., 1975) examined 78 reports dealing either with animal mortality on highways or the effects of highways on animal behavior.

A member of a committee of the American Ornithologists' Union has estimated the number of highway casualties among birds in the United States to be over 57 million annually (Aldrich 1975). In England Hodson (1962) suggested birds became casualties along highways for the following reasons: feeding on the remains of other highway victims, or on earthworms which frequent highway surfaces after a rain--crows, ravens, etc.; use of the bordering kerb-stone of highways as "anvils" for breaking snail shells--song thrushes (*Hylocichla* spp.) dust-bathing or taking grit from roads--game birds, finches and sparrows; low-flying birds being hit as they cross the roads--finches, sparrows, game birds, thrushes, and hirundines (swallows) in particular; pursuit of flying insects; displaying on the road during the breeding season--English blackbird; young of ground-nesting species being killed as they are led across busy roads by their parents--partridge; barn owls (*Tyto alba*) swooping towards a moving vehicle light, especially during the breeding season; indecision on the part of some birds when crossing roads ahead of traffic; and striking telegraph wires beside a road, then falling to the highway surface and being crushed by a passing vehicle.

With respect to big game animals, Thompson (1966) indicated that on the basis of a national survey, the 48 states reported an estimated loss of 119,198 deer (*Odocoileus* spp.), 108 elk (*Corvus canadensis*), 229 antelope, 37 bear (*Ursus* spp.) and 4 mountain lions (*Felis concolor*) in 1966. Puglisi (1974) reported that there were approximately 130,000 deer-vehicle accidents annually, resulting in an estimated national property loss in excess of $34,500,000. In Colorado, Pojar, et al. (1972) estimated that the number of deer killed accidentally on the highways equals from 5 to 10 percent of the annual legal harvest. In Oregon, based on known mortality of marked deer, those killed on the highway amounted to 3.8 percent of the number killed legally by hunters (Zalunardo, 1965), and in Wisconsin, the white-tailed deer (*O. virginianus*) highway mortality was estimated to be less than one percent of those taken by hunters in the period 1946 through 1956 (Jahn 1959).

From our review of the literature, it appears that big game highway mortality is highest where high-speed highways cross wintering concentration areas; where the highway rights-of-way constitute attractive feeding areas or the highways intersect seasonal migration routes or are between cover and feeding areas other than rights-of-way; and along sections of highway that lay in troughs formed by steep median strips and in steep rights-of-way where troughs end by a lowering of the median strips. In the case of antelope, Ward (1975) found that along Interstate 80 in Wyoming most highway mortality occurs in the spring when the animals can cross over the usually prohibitive right-of-way fences because of deep snow. He indicated that elk mortality occurs mostly at night, and that both elk and antelope are reluctant to use underpasses.

Large tolls of smaller mammals such as rabbits (*Sylvilagus* spp.), squirrel (*Sciurus* spp.), opossum (*Didelphis marsupialis*), skunk (*Spilogale putorius*, *Mephitis* spp., *Conepatus leuconotus*) muskrat (*Ondatra zibethica*), woodchuck (*Marmoto monax*), and raccoon (*Procyon lotor*) are taken on the highways annually. Some of the mortality may be associated with increased activity that occurs during the breeding season and periods of dispersal, or emergence from hibernation in the case of hibernating mammals.

Similarly, large numbers of amphibians and reptiles are killed. J.J. van Gelder (1973) provides an example with the common toad crossing a road during the breeding season. He reports on an apparently well designed study in the Netherlands where it was estimated that about 29 percent of the toads were run over. On this basis, Van Gelder calculated that as many as 9 adult toads out of 10 in the population might be killed if the traffic volume were 1 car a minute rather than 10 cars per hour.

Impressive as some of these estimates of highway wildlife mortality are, it is probable that for most species the loss is not significant biologically. This is because a relatively small proportion of the ranges of most wildlife species are affected by the highways. In the case of rare and endangered species, highways and the development that frequently accompanies them may be a more serious problem. Of concern, also, is that four-lane divided highways may be effective barriers to the dispersal of some small animals and tend to disrupt the gene flow between populations on either side of the highway (Oxley, et al., 1974).

Dead animals on the highway are esthetically displeasing to motorists, and in the case of big game-vehicle collisions, costly in property damage and in injury or loss of life to humans. On the other hand, live animals that can be seen by motorists traveling along a highway can add greatly to the enjoyment of their trip.

OTHER RELATIONSHIPS BETWEEN THE HIGHWAY SYSTEM AND FISH AND WILDLIFE

In addition to the direct loss of habitat on the one hand and the creation of habitat on the other, and in addition to extensive highway mortality sustained by wildlife, the construction, maintenance, and operation or use of highways by man have other effects, some of them indirect. Although limited access highways in some areas may tend to render less useful the roads by which hunters formerly gained access to hunting areas (Hancock 1963), construction of new roads generally is followed by residential, business, or industrial development, or, at least, more people pressure on wildlife and wildlife habitat.

DeLeonardis (1970) described some of the impacts expected from the Alaska pipeline and related road developments. High fences built along highways, while reducing traffic mortality of big game, may, at times, interfere with seasonal migrations of these species.

Other environmental effects that may merit additional comment are soil erosion and sedimentation, and chemical and other pollution.

Vice et al. (1969) found that highway construction areas in Scott Run Basin, Fairfax County, Virginia, varying from less than 1 percent to more than 10 percent of the basin at a given time, contributed 85 percent of the sediment. The sediment yield was about 10 times that normally expected from cultivated land, 200 times that expected from grassland, and 2,000 times that expected from forest land. Our review (Leedy et al., 1975) suggested that roadside erosion is likely to be greater along town roads than country roads; considerable effort is now being made to control erosion along State and interstate roads. Younkin (1973), who studied the relationship between highway construction and change in suspended sediment yield in stream systems, concluded that sediment supply to streams increases with rain energy, clearing and grubbing, embankment work, and proximity of construction to the stream. He believes results of his study may be employed as a means of predicting whether highway construction would be a significant pollution source for a particular site, a criterion to be considered by an engineer during highway location studies, and a basis to evaluate the effectiveness of attempts to control sediment yield from construction areas.

Many studies, including those by Whitney and Bailey (1959), and Platts (1968), and others, have shown effects of sediment disposition and movement on fish and other aquatic organisms. For example, sediment, especially in spawning areas, can cause mortality among salmonid embryos, alevins, and fry still in the gravel.

Pollutants other than soil sediments stem largely from chemicals used for highway deicing and control of vegetation, and (pollutants are from pesticides used to control insects) insects which damage vegetation on highway rights-of-way, from vehicular traffic, and from refuse thrown out of vehicles.

Field et al. (1974) reported that currently about 9 to 10 million tons (8.2 to 9.1 million metric tons) of sodium chloride, 0.3 million tons (0.27 million metric tons) of calcium chloride, and 11 million tons (9.98 million metric tons) of abrasives are used annually for highway deicing purposes. Much of this material is splashed off the road, where it affects roadside vegetation, and much salt-laden drainage gets into streams or nearby water supplies. Effects on fish and other aquatic organisms, of the salt and the ferric ferrocyanide and sodium ferrocyanide commonly used as anti-caking additives in the deicing materials, are not well documented, but cyanide ions are extremely toxic to fish (Hanes, et al., 1970). These authors pointed out, also, that a rust inhibitor added to deicing salts contains phosphorus which serves to stimulate excessive aquatic plant growth in fresh water lakes and leads to "algae blooms" and further problems. Although apparently not too common, Trianer and Karstadt (1960) diagnosed salt (NaCl) poisoning in wild rabbits, pheasants, quail, and a pigeon in Wisconsin during the winter of 1958-59. Salt spread on highways were believed to be the source in this case.

A voluminous amount of literature is being produced on pollutants from the operation of automotive vehicles, but, again, there are disappointingly few references which clearly define effects on fish and wildlife. Also, results of some studies addressing the problem seem contradictory. That there is some cause for concern, however, was brought out in a study by

Gish and Christensen (1973), who quantified the presence of certain heavy metals in earthworms collected from the soil along two Maryland highways. They found that earthworms had accumulated up to 331.4 ppm of Pb and 670.0 ppm of Zn, concentrations which they stated may be lethal to earthworm-eating animals. They observed that earthworms are food items for many birds as well as certain amphibians, reptiles, and mammals, but the toxicity of metal residues in worms to such animals has not been studied adequately.

With the present restrictions on use of pesticides for controlling insects, no discussion of their effects on fish and wildlife will be included here. Herbicides generally are less harmful to fish and wildlife than pesticides, and although much noise is generated by automotive traffic, its effects on wildlife have not been well documented. There is some speculation, however, that under certain situations, the noise level may be such as to interfere with the breeding behavior of birds. Ward et al. (1973) found that elk in Medicine Bow National Forest, near Laramie, Wyoming, spent little time feeding in areas where traffic noise from Interstate 80 was greatest. They suggested that in elk habitat, consideration should be given to keeping roads away from elk feeding sites on open meadows and along stream courses.

EFFORTS TO REDUCE UNDESIRABLE ENVIRONMENTAL IMPACTS: OPPORTUNITIES FOR FISH AND WILDLIFE ENHANCEMENT

PLANNING COOPERATION

With increasing environmental awareness and the passage of NEPA and its requirement for environmental impact statements, the Rare and Endangered Species Act, and other acts designed to provide environmental protection, greater efforts are being made to reduce unfavorable highway effects. In the case of new highways, the logical place to begin these efforts is in the very early planning stages. Better communication among biologists, ecologists, engineers, and others is needed throughout the planning process, and biologists should have continuing input in the many areas of highway construction, maintenance, and operation which have an effect on fish and wildlife species and their habitat.

Existing laws, guidelines, and directives, and the various memoranda of agreement between the Department of Transportation and the states, and between the Fish and Wildlife Service and the states, if fully implemented and adhered to closely at all levels, should go a long way towards reducing environmental damage by highways and enhancing fish and wildlife values. It seems desirable, however, to develop a fish and wildlife management policy for highway rights-of-way, and other aspects of the highway system, which relates to fish and wildlife. This should include goals and objectives and indicate what kinds of wildlife should be encouraged to use highway rights-of-way and, perhaps, what species should be discouraged.

HIGHWAY RIGHT-OF-WAY VEGETATION MANAGEMENT

The management of the vegetation along nearly 3.9 million miles (6,275,100 Km) of the nation's roads and streets requires much manpower, equipment, materials, time, and money. The way in which the vegetation is managed--the extent, size, types, mixtures, and condition of the plants, the amounts and kinds of herbicides, insecticides, and fertilizers used, the mowing and cutting schedules, and whether or not burning is practiced--has an important bearing on the right-of-way as wildlife habitat, as well as the effectiveness of the vegetation for erosion control, esthetics, and possibly, noise and pollution control.

To date, relatively little attention has been give to wildlife values in the management of highway right-of-way vegetation. Soil erosion control is viewed as one of the major functions of vegetation management along highways. Much consideration is given, also, to controlling vegetation so it will not obstruct the range of view required for safe driving. Considerable attention is being given to esthetic values of plants, particularly along interstate highways and parkways. These are all important objectives and methods of attaining them are being improved constantly through research. Yet it would seem that with input from biologists and plant ecologists, these same objectives could be accomplished, along with enhancement of wildlife values.

It is encouraging to note that there is a trend towards use of native vegetation for roadside plantings. Also, the U.S. Department of Transportation is encouraging research to determine what species or varieties of shrubs are best suited for multipurpose roadside plantings.

The grass that is a common feature of most highway rights-of-way is not a total loss to wildlife, but must it occupy so much of the right-of-way and be mowed so often and so closely? Oetting and Cassel (1970) found that ducks responded quickly to cessation of mowing when alternate miles of the right-of-way and half of the interchange triangles were left unmowed along an interstate highway in North Dakota. Seventy-four percent of the ducks chose unmowed nesting sites. On the basis of their studies, these authors strongly recommended no mowing of ditch bottoms or back slopes, minimal mowing of inslopes, and no mowing before 20 July to enhance waterfowl nesting and to reduce maintenance costs of highway rights-of-way in regions where ducks nested. It is also interesting that 82 percent of the 182 motorists interviewed had not noticed the mowed-unmowed conditions of the highway (Oetting and Cassel, 1970).

A news item dated 15 June 1976 indicated that the South Dakota Board of Transportation had set a new policy which will permit mowing of state roadsides east of the Missouri River only between 10 July and 1 September in a move to protect pheasants. This short mowing period in eastern South Dakota will allow nesting to be completed and yet permit a regrowth of nesting cover for the following spring.

Highway vegetation control is accomplished by mowing, cutting, burning, and the use of herbicides, the latter often in combination with the other measures. A long-time author and consultant on right-of-way vegetation management, Egler (1953a, 1953b, 1957) suggested that the first step in such management should be the discriminate elimination of the undesirable woody plants through selective basal spraying, which is as cheap as blanket spraying in the first conversion stages of the vegetation to trees, and provides edge effects desirable for wildlife. Indiscriminate blanket spraying with herbicides often results in the root kill of desirable shrub cover before the tree roots are killed, and the shrubs do not seed again. Egler further points out that most of the upland grasses are easily invaded by a few species of trees, in contrast to certain shrublands which are relatively sealed against tree invasion. He recognizes that no one treatment is the whole answer, and that treatments must be adapted to the site and the vegetation.

Niering and Goodwin (1974) described how, through employment of ecologically sound techniques and selective application of herbicides, shrub communities with high stability and wildlife values have been established on a demonstration area in Connecticut. They indicated that clones of several shrubs experience virtually no tree invasion and listed among such shrubs: huckleberry (*Gaylussacia baccata*), greenbriar (*Smilax* spp.), low bush blueberry (*Vaccinium angustifolium*), common witch-hazel (*Hamamelis virginiana*), speckled alder (*Alnus rugosa*), sheep laurel (*Kalmia angustifolia*), gray dogwood (*Cornus racemosa*), and nannyberry (*Viburnum lentago*). Pure stands of little bluestem (*Schizachyricum scoparium*) grass exhibit remarkable stability also.

Tester and Marshall (1962) recommended a 4-year rotation of spring burn, no treatment, graze and no treatment, to maintain remaining tracts of native grasses valuable for prairie chickens in Minnesota. With perhaps some modification, this type of program might be applicable to maintaining some of the remaining native grasses in odd tracts within highway rights-of-way.

Although, for safety reasons, it is necessary to keep down tall tree growth in much of the rights-of-way, there are places back from the road where trees are desirable--including an occasional dead tree with branches suitable for perching, wood suitable for insect-gleaning birds, and cavities suitable for hole-nesting birds or other animals. Often such trees are removed routinely in tree sanitation, trimmings and cleanup operations. The red-cockaded woodpecker (*Dendrocopos borealis*) presently on the endangered list, may be seen utilizing mature pines infested with a heart rot fungus, but left standing along interstate highways in some southeastern states.

The subject of vegetation management is too complex to treat in detail here, but there is need for biologists who know about wildlife requirements to make more input into this phase of highway planning and maintenance.

WATER DEVELOPMENTS AND MANAGEMENT

Jordan (1968), in discussing the interstate highway construction program, estimated that enough material is being excavated to bury Connecticut knee-deep and that the sand, gravel, and stone going into roads would build a wall 9 feet (2.7 m) thick and 50 feet (15.2m) high around the world. Some of this material is obtained along the highway and creates borrow-pits, some of which fill with water and result in lakes of value to fish and wildlife, such as along Interstate 80 in Nebraska (Steen 1966) and along Interstate 29 in southwest Iowa (Hill 1975). Some of the material may be taken from stream beds and create large holes, resulting in the accumulation of stagnant water without the necessary oxygen for aquatic life. When used for highway fills which block drainage, wetland areas may be created which, also, may have value to fish and wildlife. As pointed out by Carlozzi et al. (1971), however, wetlands inadvertently created in the course of highway construction generally are poor in productivity as a result of poor location, morphometry, site preparation, or a combination of these factors. Hence, biologists have an opportunity to provide the kind of information that would increase the value of such areas for fish and wildlife. Decisions on the potential fish and/or wildlife uses to be made of the impoundments or wetlands should be made in the planning stages for highway route selection and construction, i.e., whether they have greater potential for fish, waterfowl, shore birds, furbearers, or a combination of them.

Heusmann (1970, 1971, 1973) has discussed some of the engineering aspects involved and has suggested that the desired use of such impoundments as wildlife areas can be promoted by voluntary cooperation, regulation by police powers, and by acquisition. Moulton (1970) has made management recommendations for increasing the fishery potential of existing borrow-pits along Interstate 91 near Whately, Massachusetts, and developing guidelines for future construction and management to enhance fish production.

Stream channelization in connection with highway construction should be avoided when possible, or if streams are channelized, they should be rehabilitated to include meanders and other features resembling as nearly as possible the original conditions. Patrick (1973) observes that snagging and removing vegetation from banks produces profound changes in the ecosystems of the streams, and that removal of floating debris eliminates an important habitat for aquatic organisms. She states further: "...when a channel is straightened the banks are often riprapped with quarried stone at a vertical angle. The result is that the sun reaches the water surface for an insufficient time to support algae growths that are important as food for animals in the ecosystems. If the banks were riprapped at an angle of 30 to 45 degrees with natural water-worn stones, current patterns would be produced that favor native stream organisms... If dredging is done, attempts should be made to restore the natural contour of the channel bed, for example, create pools and slack-waters in shallow streams or restore the roughness of the channel bed. That would interfere very little with the carrying capacity of the channel under flood conditions, but would greatly improve the bed habitats for species occupancy."

Considerable headway in stream preservation and rehabilitation has been made in Montana (Peters 1970) by realignment of proposed bridges to avoid encroachments on rivers, designing and building of meanders so the channel is as long after construction as before, building, and/or planning of extra bridges to preserve natural meanders, replacement of brushy floodplain vegetation removed to facilitate construction, and limiting of channel excavation to those times of the year when trout are not spawning and eggs are not in the redds. In Utah, Barton and Winger (1973) found that rehabilitation structures such as deflectors and check dams in channelized streams helped produce hydrologic conditions similar to those in unchanged portions of the streams. Also, Shelton and Pollock (1966), studying under controlled conditions the effects of siltation on fall chinook salmon (Oncorhynchus tshawytscha) eggs, suggested that on the basis of their research, a siltation control system consisting of a flushable sandtrap and settling basin constitutes the most economical means of reducing the amount of sediment entering fish incubation channels or similar areas. Presumably, however, for larger streams, keeping siltation or sedimentation at a minimum will continue to depend upon soil erosion control through vegetative management, structural, and other methods used in connection with highway construction and maintenance.

Several authors, including Kay and Lewis (1970), Lewis and Kay (1970), Gebhards and Fischer (1972), Evans and Johnston (1974), Dryden and Jessop (1974) and Oregon Wildlife Commission (1975) have discussed the problems of blockage of fish passage by culverts and have provided guides for use in designing culverts or otherwise dealing with this problem. It is desirable that biological information be provided to the highway planners and engineers, early in the planning process, regarding the physical capabilities of fish for swimming past barriers and the identification of streams where blockage of fish passage by culverts may be a problem.

With respect to pollution, motor vehicular traffic is responsible for deposition of substantial amounts of materials on roadways, including toxic heavy metals, asbestos, and slowly biodegradable petroleum products and rubber. Roadways, particularly in urban areas where there are curbs, are efficient collectors of particulate materials; also, they are efficient in transporting these materials and deicing chemicals through runoff. As pointed out by Shaheen (1975), runoff from urban roadways induces shock effects upon receiving waters as the accumulated nutrients, toxic, and oxygen-demanding substances are abruptly introduced during storm events. Changes in the downstream biota may result. Shaheen mentioned as possible ways of reducing these shock loads of materials into streams: (1) selection of the roadway sites in such a manner as to minimize the roadway areas drained directly into the receiving body of water, (2) utilization of low curbs where the road is adjacent to unpaved areas which are flat or gently sloping away from the street surface to facilitate the deposition of the dust and dirt into grass and gravel areas and thus reduce the deposition in receiving waters, (3) consider the use of porous pavement in areas where climate and soil types permit, (4) intensify and improve street cleaning operations to reduce urban roadway runoff effects, (5) design curbs and gutters to facilitate concentrations of particulate material and collection of same, and (6) investigate various approaches to detention and storage of storm runoff and separation of solids from stormwater.

MEASURES FOR REDUCING HIGHWAY WILD ANIMAL MORTALITY AND ACCIDENTS

Highway wild animal mortality and animal-vehicle accidents usually result from the presence of the animals on or immediately above the paved surface of the highway at the same time a vehicle passes by. A few vehicular accidents may occur when the driver gets too interested in observing wildlife along the road. In any event, the location and type of road in relation to adjacent habitat conditions and wildlife populations have a bearing on the number of accidents and the extent of wildlife mortality. As has been noted, the type of vegetation in highway rights-of-way and adjoining areas, the topography, snow conditions, and whether a highway crosses the big game migration route or a deer wintering area all may be factors affecting the accident rate.

Vehicular collisions involving big game cause considerable property damage and some loss of human lives; thus, more research--mostly with support of the Federal Highway Administration--has been done to reduce accidents involving deer and other big game than for other species killed in greater numbers, but without so much hazard to humans. Fencing, highway underpasses to permit the animals to cross beneath the highway, traffic signs to warn drivers of animals, highway lighting schemes, roadside mirrors which cause flickering lights when cars pass through animal-accident prone spots at night, and other measures for reducing the number of animal-vehicle accidents have been tried with varying degrees of success.

Reed et al. (1973) reported that the number of mule deer crossings at a site on Highway 82 in Colorado was reduced by 82 percent during the first March-May period after installation of a 1.1 mile (1.8 Km) 8-foot (2.4 Km) fence, and the annual highway deer kill at that location was reduced by 61 percent. One-way gates, opening outward, may enable deer to escape from a roadway (Reed et al. 1974) whenever they go around the end of a deer-proof fence or come in from the opposite side and become trapped or funneled next to a highway.

Based upon a study of deer mortality along Interstate 80 in Pennsylvania, Bellis and Graves (1971) suggested that: (1) deer fences along highways in forested regions be continuous over long stretches to prevent deer from going around the ends and being funneled along the highway by the fences; and (2) if the fences were constructed close to the highway, rather than where the right-of-way merges with the forest some distance away, the deer might be less likely to cross the fence because their feed would be available outside the fence rather than next to the road.

Although some success has been attained by the use of fences, solutions to the big game-vehicle conflict are still inadequate. Other measures have met with even less success, including limited experiments with plantings of vegetation thought to be unattractive to big game.

In connection with the heavy losses of toads as they cross highways during the breeding season, Van Gelder (1973) reports that in addition to authorities closing or blocking a road temporarily, an approach is to help the toads across that part of the road used in their migration. He states this can be done through use of barriers in conjunction with either a tunnel underneath the road, or pitfalls into which the toads fall and then are removed daily during the migration period to the other side of the road. He reports that the latter method is preferred in in Switzerland.

OTHER MANAGEMENT CONSIDERATIONS

The importance of route selection for new highways in order to minimize erosion, sedimentation, and other pollution problems, reduce the amount of stream channelization required, and hold down wild animal mortality on highways, has been mentioned. The identification and mapping of ecosystems especially sensitive to disturbance by highway construction and use, including habitat critical for the conservation of rare and endangered plant and animal species, should precede the selection of road location and be a part of the planning process. A viable alternative route possibly could save a species or unique biological community. Information available on the habitat requirements, behavior, and range of an endangered animal species might conceivably permit the species to be saved by transplanting the animals to other suitable habitat outside the highway corridor, if alternative routing of the highway is not possible. This has been attempted in the case of desert tortoises (Gopherus agassizi) by the California Division of Highways (now Caltrans) in connection with State Highway 58 in San Bernardino County, California. Due to the many failures experienced with transplant operations in the fish and wildlife field, however, it is preferable to avoid habitat disturbance when possible and not rely on transplanting of species from their currently used habitat.

Some of the methodologies discussed at this symposium on classifying, inventorying, and analyzing fish and wildlife habitat on other sites may also have application for the nation's highway system. I hope some of the ecological relationships and management implications mentioned in this rather lengthy paper serve to stimulate more research and management effort on highway and related habitats.

LITERATURE CITED

Aldrich, L., Chairman, 1975. Report on the Ornithologists' Union ad hoc committee on scientific and educational use of wild birds. Auk 92 Suppl.3: 1A-27A.

Baker, H., 1971. Nutritional strategies of myomorph rodents in North American grasslands. Mammal. 52(4):800-805.

Barton, J.R., and P.V. Winger, 1973. Rehabilitation of a channelized river in Utah. pp. 1-10. In: Hydraulic Engineering and the Environment. Proc. of the Hydraulic Specialty Conf., Bozeman, Montana.

Bellis, E.D., and H.B. Graves, 1971. Deer mortality on a Pennsylvania interstate highway. Wildl. Manage. 35(2):232-237.

Broadbrooks, E., 1958. Northward extension of the kangaroo rat in Washington. Mammal. 39(2):299-301.

Carlozzi, C., J.G. Fabos, L.C. Mainzer, R.J. Reed, K.L. Bergstrom, P.R. Dommel, J.C. Moulton, and W.E. Rogers, 1971. Enhancement of Ecologic and Aesthetic Values of Water Associated with Interstate Highways. Water Resour. Cen., Univ. of Massachusetts at Amherst, Publ. 19, 114 pp.

Council on Environmental Quality, 1974. The Fifth Annual Report of the Council on Environmental Quality. U.S. Government Printing Office, Washington, D.C., 597 pp.

Dalke, P.D., D.B. Pyrah, D.C. Stanton, J.E. Crawford, and E. Schlatterer, 1960. Seasonal movements and breeding behavior of sage grouse in Idaho. Trans. Am. Wildl. Resour. 25:396-407.

Davis, Russell, and E. Cockrum, 1963. Bridges utilized as day-roosts by bats. Mammal. 44(3):428-430.

DeLeonardis, Salvatore, 1970. Industrialization of the north and its effects on wildlife resources. Federal-Provincial Wildl. Conf. 34:46-49.

Denton, J., 1967. The barn swallow nesting in Columbia and Lincoln Counties, Georgia. The Oriole 32(3):32-33.

Dryden, R.L., and C.S. Jessop, 1974. Impact Analysis of the Dempster Highway Culvert on the Physical Environment and Fish Resources of Frog Creek. Environ., Canada, Res. Manage. Branch, Cen. Region Tech. Rep. Ser. Cen/T-74-5. 59 pp.

Egler, F. E., 1953a. Our disregarded rights-of-way--ten million unused wildlife acres. Trans. N. Wildl. Conf. 18:147-157.

Egler, F. E., 1953b. Vegetation Management for Rights-of-Way and Roadsides. pp. 299-322. In: Annu. Rep. Board of Regents, Smithsonian Instit., Publ. 4149, U.S. Govt. Printing Office.

Egler, E., 1957. Rights-of-way and wildlife habitat: a progress report. Trans. N. Am. Wildl. Conf., 22:133-144.

Egler, F. E. and S. R. Foote, 1975. The plight of the "right-of-way" domain--victim of vandalism. Future Media Serv., Mt. Kisco, New York, Part I, 294 pp.; Part II, 160 pp.

Evans, W.A. and F. B. Johnson, 1974. Fish Migration and Fish Passage--A Practical Guide to Solving Fish Passage Problems. U.S.D.A. For. Serv.-Region 5. 43 pp.

Field, Richard, E. Masters, N. Tafuri, and J. Struzeski, Jr., 1974. Water Pollution and Associated Effects from Street Salting. (Abridgement of 1971 EPA Report, Environmental Impact of Highway Deicing), pp. 40-41. In: Transportation Res. Record 506, Transportation Res. Board, Washington, D.C.

Gebhards, Stacy and Jack Fischer, 1972. Fish Passage and Culvert Installations. Idaho Fish and Game Dept. 12 pp.

Gish, D., and R.E. Christensen, 1973. Cadmium, nickel, lead, and zinc in earthworms from roadside soil. Environ. Sci. and Technol. 7:1060-1062.

Graham, Ed. H., 1947. The land and wildlife. Oxford University Press, New York. 232 pp.

Hancock, N.V., 1963. Impact of interstate highways upon the wildlife resource. pp. 183-187. In: Proc. Annu. Conf. Western Assoc., State Game and Fish Commissioners.

Hanes, R.E., L.W. Zelazny, and R.E. Blaser, 1970. Salt Tolerance of Trees and Shrubs to Deicing Salts, pp. 16-18. In: Highway Res. Record 335, Highway Res. Board, Washington, D.C.

Harmon, K.W., 1971. Prairie potholes. Natl. Park and Conserv. Mag. 45(3): 25-28.

Heusmann, H.W., 1970. Highway impoundments--planning, use and control. The Massachusetts Heritage, 8(1):1-4.

Heusmann, H.W., 1971. Highway Impoundments: a Technological Bonus. Mass. Div. of Fish. and Game, Westboro, Massachusetts.

Heusmann, H.W., 1973. How to create wildlife habitat from highway construction. Catalyst 3(4):17-19.

Hill, K. R., 1975. I-29 Chain of lakes. Iowa Conservationist 34(6):4-6.

Hodson, N.L., 1962. Some notes on the causes of bird road casualties. Bird Study 9(3):168-173.

Huey, L.M., 1941. Mammalian invasion along the highway. Mammal. 22(4): 383-385.

Jahn, L.R., 1959. Highway mortality as an index of deer-population change. J. Wildl. Manage. 12(2):187-196.

Jordan, P., 1968. Our growing interstate highway system. Natl. Geographic 133(2):194-219.

Kay, A.R. and R.B. Lewis, 1970. Passage of Anadromous Fish through Highway Drainage Structures. California Dept. Public Works, Div. Highways, District 01 Hydraulics Sec. Res. 629110, 15 pp.

Leedy, D.L. 1975. Highway-Wildlife Relationships: Vol. 1, A State-of-the-Art Report. Rep. FHWA-RD-76-4, Fed. Highway Adm., Washington, D.C., 193 pp.

Leedy, D.L., T.M. Franklin, and E.C. Hekimian, 1975. Highway-wildlife Relationships Vol. 2, An Annotated Bibliography. Rep. FHWA-RD-76-5, Fed. Highway Adm., Washington, D.C., 417 pp.

Lehmann, V.W., 1968. The Attwater prairie chicken, current status and restoration opportunities. Trans. N. Am. Wildl. Nat. Resour. Conf., 33:398-407.

Lewis, R.B. and A.R. Kay, 1970. Passage of Anadromous Fish through Highway Drainage Structures. California Div. H-3-4.

Linder, R.L., D.L. Lyon, and C.P. Agee, 1960. An analysis of pheasant nesting in south-central Nebraska. Trans. Wildl. Nat. Resour. Conf. 25:214-230.

Martin, R.F., 1974. Syntopic culvert nesting of cave and barn swallows in Texas. The Auk 91(4): 776-782.

Mayer, H., 1958. Cities, transportation, and technology, pp. 493-502. In: A Stefferud (ed.), Yearbook of Agriculture, 1958. U.S. Dept. of Agric., Washington, D.C.

Michael, E.D., 1971. Starling nesting in rocky cliffs. Bird-Banding 42(2):123.

Michael, E.D., C.R. Ferris, and E. G. Haverlack, 1976. Effects of highway rights-of-way on bird populations, pp. 254-261. In: Robert Tillman (ed.), Proceedings of the First National Symposium on Environmental Concerns in Rights-of-Way Management. Dept. Wildl. and Fish., Mississippi State, Mississippi, 335 pp.

Miller, J.W., 1975. Much ado about starlings. Nat. Hist. 84(7):38-45.

Miller, J.P., and B.B. Powell, 1942. Game and Wild-fur Production on Agricultural Land. U.S. Dept. Agric., Circ. 636, 58 pp.

Moulton, J.C., 1970. The Fishery Potential of Four Aquatic Environments Created by Interstate Route 91 Construction in Massachusetts. M.S. Thesis, Univ. Massachusetts, 86 pp.

Niering, W.A., and R.H. Goodwin, 1974. Creation of relatively stable shrublands with herbicides: arresting "succession" on rights-of-way and pastureland. Ecology 55(4):784-795.

Oetting, Robert B., and J. Cassel, 1970. Effects of I Interstate right-of-way mowing on wildlife, snow buildup, and motorist opinion in North Dakota: a preliminary report, pp. 52-59 In: Highway Res. Rec. 335, Highway Res. Board, Washington, D.C.

Oetting, R.B., and J. F. Cassel, 1971. Waterfowl nesting on interstate highway right-of-way in North Dakota. J. Wildl. Management 35(4):774-781.

Oregon Wildlife Commission, 1975. Draft of Oregon Wildlife Commission Standards for Fish Passage at Road-Stream Crossings. Oregon Wild. Comm., Portland, Oregon, 38 pp.

Oxley, D.J., M.F. Fenton, and G.R. Carmody, 1974. The effects of roads on populations of small mammals. J. Apl. Ecol. 11(1):51-59.

Patrick, Ruth, 1973. Effects of channelization on the aquatic life of streams, pp. 150-154 In: Environmental Considerations in Planning, Design and Construction. Highway Res. Board, Div. Engin. Natl. Counc., Natl. Acad. Sci.--Natl. Acad. Engin., Spec. Rep. 138, 161 pp., Washington, D.C.

Peters, J.C., and William Alvord, 1964. Man-made channel alterations in thirteen Montana streams and rivers. Trans. N. Am. Wildl. Nat. Resour. Conf. 29:93-102.

Peters, J.C., 1970. Operations since 1963 under Montana's stream preservation law. Trans. Wildl. Nat. Resour. Conf. 35:276-284.

Platts, W.S., 1968. South Fork Salmon River, Idaho, Aquatic Habitat Survey with Evaluation of Sediment Accruement, Movement, and Damages. U.S.D.A. For. Ser. (Boise, Idaho). 135 pp.

Pojar, T. M., D. F. Reed, and T.C. Reseigh, 1972. Highway construction--motorist and deer safety. Proc. Western Assoc. State Game and Fish Commissioners Conf. 52:268-271.

Puglisi, M.J., 1974. Pennsylvania conducts study of deer-vehicle collisions. Traffic Safety (April), p. 25.

Reed, D.F., J. Pojar, W.R. Heicher, L.L. Green, J. K. Moser, and T.N. Woodard, 1973. An Evaluation of Deer-Proof Fence Length Required to Prevent Deer Movements on or Across High Speed Highways, pp. 197-202 In: Proj. W-38-R-27, Res. Rep. Colorado Div. Wildl., Denver.

Reed, D.F., M. Pojar and T. N. Woodard, 1974. Mule deer responses to deer guards. J. Range Manage. 27(2):111-113.

Shaheen, D.G., 1975. Contributions of Urban Roadway Usage to Water Pollution. Office Res. and Dev., U.S. Environ. Protection Agency, Technol. Ser., EPA-600-2/75-004, 118 pp.

Shelton, J.M. and R.D. Pollock, 1966. Siltation and egg survival in incubation channels. Trans. Am. Fisheries Soc. 95(2):183-187.

Steen, M.O., 1966. Elements of successful state plans. Trans. N. Wildl. Nat. Resour. Conf. 31:374-354.

Stewart, R., and H. A. Kantrud, 1973. Ecological distribution of breeding waterfowl populations in North Dakota. J. Wildl. Manage. 37(1):39-50.

Tester, J.R., and W. H. Marshall, 1962. Minnesota prairie management techniques and their wildlife implications. Trans. Wildl. Nat. Resour. Conf., 27:267-287.

Thompson, F. A., 1966. Deer on Highways--1966 Supplement. New Mexico Dept. Game and Fish, State Capitol, Sante Fe, 7 pp.

Trainer, D.O., and Lars Karstad, 1960. Salt poisoning in Wisconsin wildlife. J. Am. Vet. Med. Assoc., 136(1):14-17.

Trautman, C.G., 1960. Evaluation of pheasant nesting habitat in eastern South Dakota. Trans. N. Am. Wild. Nat. Resour. Conf. 25:202-213.

U.S. Department of Agriculture, 1974. An Inventory of Fish and Wildlife Habitat Improvement Needs, Forest Service, California Region, 14 pp.

U.S. Department Interior, 1975. Task Force Report on Effects of Road Construction on Wetland Wildlife Habitat. Fish and Wild. Serv., Twin Cities, Minnesota, 14 pp.

U.S. Department of Transportation, 1973. Highway Statistics-1973. U.S. Dept. Transportation, Federal Highway Adm., Highway Statistics Div., Office Highway Planning., Govt. Printing Office, Washington, D.C., 270 pp.

Van Dersal, W.R., 1943. The American Land--Its History and Uses. Oxford University Press, New York, 215 pp.

van Gelder, J. J., 1973. A quantitative approach to the mortality resulting from traffic in a population of Bufo bufo L. Oecologia 13:93-95.

Vice, R.B., H.P. Guy, and G.E. Ferguson, 1969. Sediment Movement in an Area of Suburban Highway Construction, Scott Run Basin, Fairfax County, Virginia, 1961-64. U.S. Geological Surv. Water-Supply Pap. 1591-E, 41 pp.

Wallace, G. O., 1970, Cliff swallows nesting in Grainger County. The Migrant 41(4):77-78.

Ward, A., 1975. Effects of Highway Construction and Use on Big Game Animal Populations. Second Annu. Rep. 3F942-41-42-13-0103-33F2-3-2582, Fed. Highway Adm. and U.S. For. Ser., 59 pp.

Ward, A. Lorin, J.J. Cupal, A.L. Lea, C.A. Oakley, and R.W. Weeks, 1973. Elk behavior in relation to cattle grazing, forest recreation, and traffic. Trans. N. Am. Wildl. Nat. Resour. Conf., 38:327-337.

Whitney, A.N., and J.E. Bailey, 1959. Detrimental effects of highway construction on a Montana stream. Trans. Am. Fish.Soc. 88(1):72-73.

Wooten, H.H., and J. R. Anderson, 1958. The uses to which we put our land, pp 53-63. In: A. Steffernd (ed.), Yearbook of Agriculture, 1959. U.S. Dept. Agric., Washington, D.C.

Younkin, L.M., 1973. Effects of highway construction on sediment loads in streams, pp. 82-93 In: Soil Erosion--Causes and Mechanisms, Prevention and Control, Spec. Rep. 135. Highway Res. Board, Washington, D.C.

Zalunardo, R.A., 1965. The seasonal distribution of a migratory mule deer herd. J. Wildl. Manage. 29(2):345-351.

USE OF CRITICAL PARAMETERS FOR EVALUATING WILDLIFE HABITAT[1]

Rollin D. Sparrowe
U.S. Fish and Wildlife Service
Department of Interior
Washington, D.C. 20240

Bettina Flood Sparrowe
Washington, D.C. 20240

Abstract: This paper reviews some contemporary methods of objectively rating the value of wildlife habitats for the purpose of negotiating trade offs with proposed developments, identifies concepts which these methods have in common, and presents preliminary results of developing a handbook for habitat evaluations to supplement the Habitat Evaluation Procedures (HEP) being developed by the U.S. Fish and Wildlife Service, Division of Ecological Services, and cooperating state agencies. Currently active methods of evaluating wildlife habitats, including HEP, are based on assessing the capability of that habitat to provide food, water, cover, and any special reproductive requirements of animals common to that geographic area. Preliminary results of testing a set of carefully developed evaluation criteria at a field site in Missouri showed that a handbook of such criteria can save field time, standardize scores, and decrease variation in scoring. More intensive testing and further analysis of habitat evaluations must be done to improve and standardize judgment-based evaluations of wildlife habitat in the field.

INTRODUCTION

During the past several years Federal and state agencies and private organizations have been working to develop professionally acceptable and reasonably uniform methods of judging the value of wildlife habitats threatened by water and other resource developments. The extent of the problem with water resource development pressures on fish and wildlife habitats has been documented through extensive congressional hearings on channelization and other stream alteration practices, such large-scale government studies as the June 1973 "Report of the National Water Commission," the proliferation of environmental impact statements (EIS), and intensive activities in the public and private sector. It is not correct, however, to assume that everyone in resource management and related areas of biological science understands the practical problems faced by natural resource agencies and private organizations trying to halt the constant attrition of fish and wildlife habitats.

---

[1] Contribution from the Missouri Cooperative Wildlife Research Unit (U.S. Fish and Wildlife Service, Missouri Department of Conservation, Wildlife Management Institute, and University of Missouri-Columbia, cooperating). This work was funded principally by Research Contract USDI 14-16-0008-2014 between the U.S. Fish and Wildlife Service and the University of Missouri-Columbia. Funds from the Edward K. Love Foundation were also used.

Conflicts between agencies, between resource managers and scientists, and among resource managers in the field, center around the trade offs necessary between the needs for rigorous, scientifically sound evaluation methods and the practical constraints on time, staff, and access to project sites. In spite of these conflicts, there is a clear need for commitment to strengthen our evaluation capabilities, and a recognition that we should first agree on a common set of biologically sound critical parameters of wildlife habitat for use in field evaluations.

As possible background for this paper, several biologists suggested a "peer review" of the specific problem of identifying critical parameters of wildlife habitat. Correspondence with experienced biologists in the Cooperative Wildlife Research Units, and at universities, generally failed to identify uniform parameters of habitats which they judged to be critical to any habitat evaluation. Several felt the problem was too broad to respond to; most preferred to speak in terms of a single species; and many fell back on measuring vegetation, diversity, succession, and broad aspects of ecosystems. The conclusion from these and other contacts with biologists experienced with many kinds of animals and ecosystems, is that one of our basic problems is still communication of what we need and why we need it.

The symposium brochure stated that we need "a system compatible with the varied interests and useable by their advocates." The reason for needing such a system is clear when one appraises the alarming rate at which wildlife habitat is being lost to various types of land and water developments. Many types of evaluation systems are currently being developed without common goals and objectives, thus impeding progress toward the type of system this symposium is calling for.

This paper reviews some contemporary methods of objectively rating habitats for the purpose of making trade offs with proposed developments, identifies concepts which these methods have in common, and presents preliminary results of developing a handbook for habitat evaluations to supplement the Habitat Evaluation Procedures (HEP) being developed by the U.S. Fish and Wildlife Service Division of Ecological Services and cooperating state agencies. Based on this information we draw some conclusions about current problems of blending "practical needs" with "scientific approaches" to evaluating habitat.

CONTEMPORARY EVALUATION METHODS

Most of the recently developed habitat evaluation systems attempt to use biologically sound judgment to rate habitat. These evaluations are not cast in the traditional scientific approach of hypothesis testing, but are attempts to practically approach a need and provide a value judgment which can be duplicated with a reasonable degree of precision. The product of these habitat evaluations may be expressed in dollars, numbers of animals, or extent of departure of the particular habitat from a norm, or abstract units of value, such as environmental impact units, acre value units, or habitat units. The results of evaluations presented in clearly defined abstract terms enable comparisons between and across habitat types at development sites.

"Acre-value units" were used by Hamor (1970) to evaluate impacts of water and related land resource development projects on fish and wildlife habitat. A team of biologists trained in the method and familiar with the flora and fauna of the area rated habitat characteristics on a zero through one scale for each habitat type, and multiplied this value by the number of acres of that habitat type in the project area. In order to express "acre-value units," the abstract assessments of value for the area, adjustments were made for the potential value if the area were intensively managed for wildlife. This evaluation scheme influenced the development of several methods that followed.

Dee et al. (1972) presented an Environmental Evaluation System used by the U.S Bureau of Reclamation to indicate major adverse environmental impacts. Environmental pollution, aesthetics, and human interest values were included in this system.

Daniel and Lamaire (1974) developed a habitat evaluation system for Missouri using several of Hamor's (1970) basic concepts. This system quantified the effects of development projects in terms of "habitat units." Mitigation needs were determined by calculating management potential of those areas which would be lost to the proposed project. With this method the user narratively described areas and selected a value from 1 through 10 for all species of wildlife.

A method being developed for the U.S. Soil Conservation Service (SCS) (Whitaker and McCuen 1976) judged quantity of land used, degree of interspersion of each land use type, stage of land management, and vegetation types to assess habitat quality. This system has been used experimentally on watersheds in Maryland, but has not been officially accepted by the SCS. The output from this system was expressed in "acre-value units."

Whitaker et al. (1976) developed line charts (Figure 1) which presented the array of possibilities for a given habitat characteristic (species composition of deciduous trees, moisture condition, etc.), so that each characteristic could be inventoried in the field. The line charts for each habitat characteristic were brought in from the field and used with transformation line chart overlays (Figure 2) which represented values, to the animal, of the habitat characteristic inventoried. Each habitat characteristic was weighted in accordance with its importance to the specific animal.

The U.S. Army Corps of Engineers (1976) developed a habitat evaluation system which used transformation curves, similar to those proposed by Whitaker et al. (1976), to describe habitat quality. Each habitat parameter was assigned a set of values on a curve which illustrated the effects of differences in that characteristic on all animal species. Each parameter was also assigned a weight which accounted for its relative importance within the habitat type under consideration. These values were expressed as "habitat values."

Some of the most detailed evaluation schemes in the literature deal with bird species diversity in relation to their habitats. One such method was presented by Graber and Graber (1976) in which they proposed an evaluation methodology based on nesting birds as faunal indicators. The bird fauna and associated habitats served as an index to general biological richness of sample habitats in Illinois. The method was based on the habitat replacement time, availability, rate of change in availability, amount, and the faunal and/or floral complexity. Indices to environmental value were calculated from these five factors, to present a "habitat evaluation index" and a "faunal (or floral) index." Methods like this one offer valuable ideas for the development of habitat evaluation systems for natural resource develoments, but require too much intensive field work, data collections, and detailed analysis to be practical for wide application.

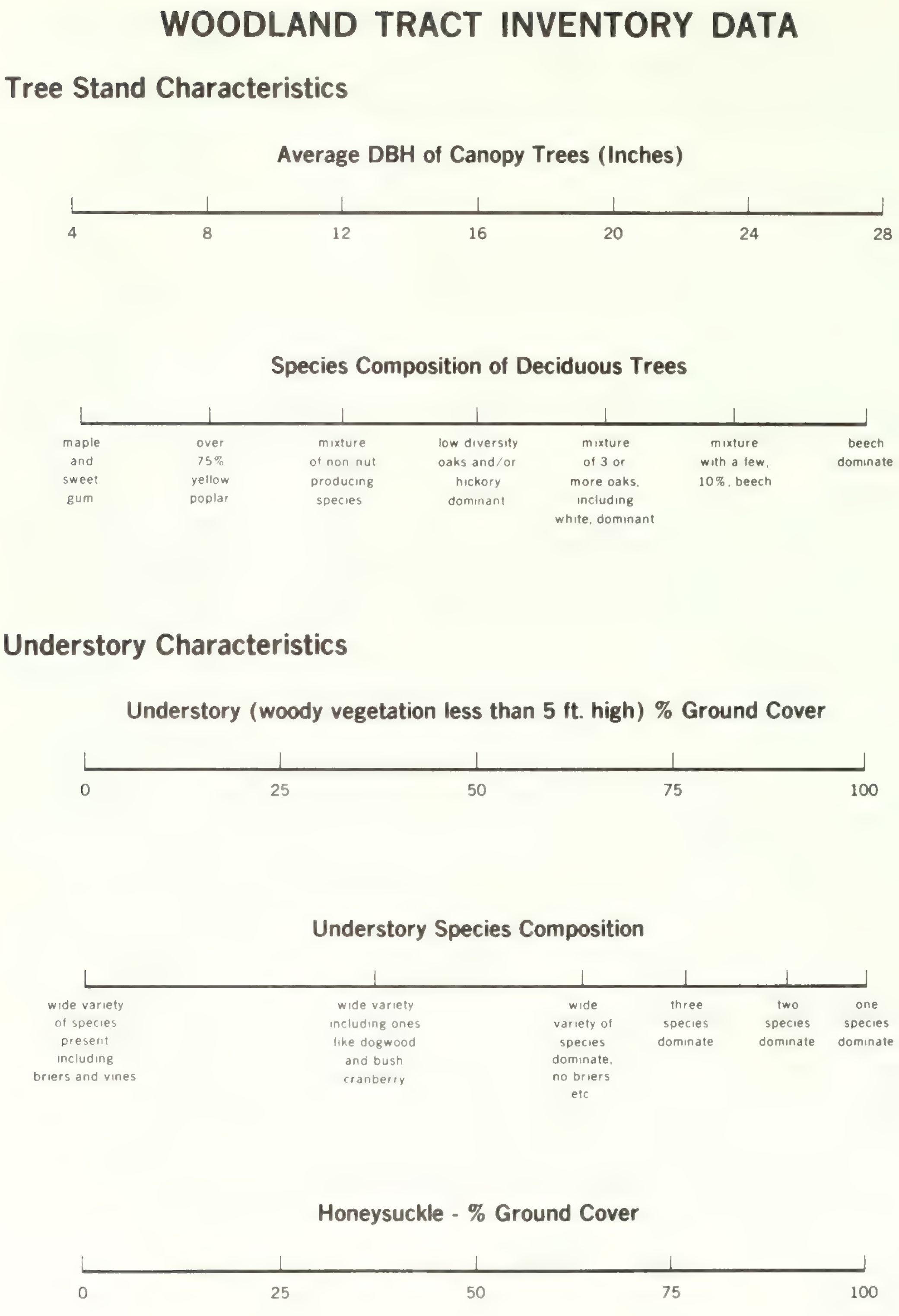

WOODLAND TRACT INVENTORY DATA
Tree Stand Characteristics
Average DBH of Canopy Trees (Inches)
4
8
12
16
20
24
28
Species Composition of Deciduous Trees
maple and sweet gum
over 75% yellow poplar
mixture of non nut producing species
low diversity oaks and/or hickory dominant
mixture of 3 or more oaks, including white, dominant
mixture with a few, 10%, beech
beech dominate
Understory Characteristics
Understory (woody vegetation less than 5 ft. high) % Ground Cover
0
25
50
75
100
Understory Species Composition
wide variety of species present including briers and vines
wide variety including ones like dogwood and bush cranberry
wide variety of species dominate, no briers etc
three species dominate
two species dominate
one species dominate
Honeysuckle - % Ground Cover
0
25
50
75
100

Figure 1. Line charts for inventorying land use, vegetative communities, and other site characteristics considered important in evaluating wildlife habitat in the Seneca Creek watershed (Whitaker et al. 1976).

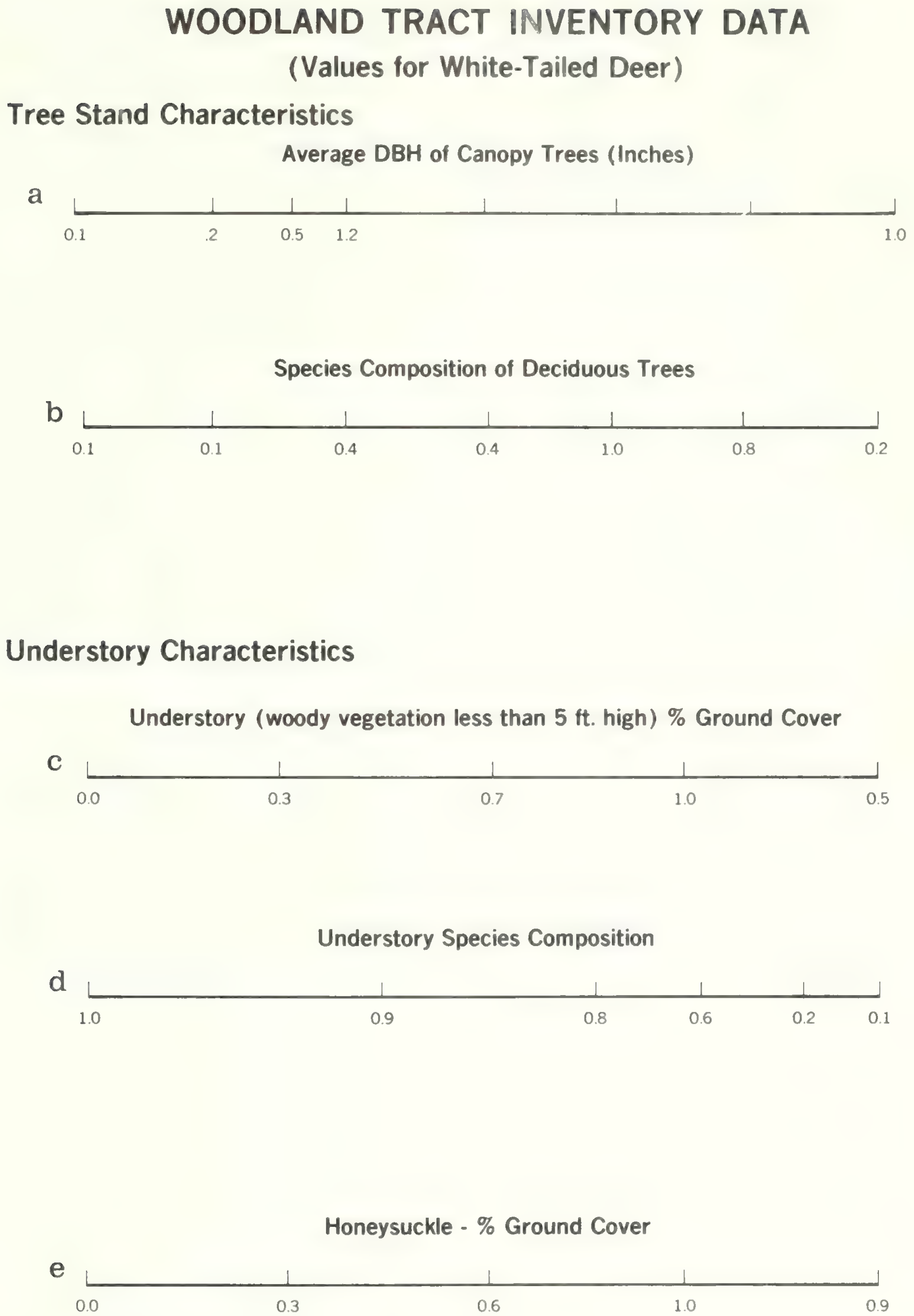


Figure 2. Transformation line charts for converting inventoried characteristics for woodland to habitat values for white-tailed deer (*Odocoileus virginianus*) in the Seneca Creek watershed (Whitaker et al. 1976).

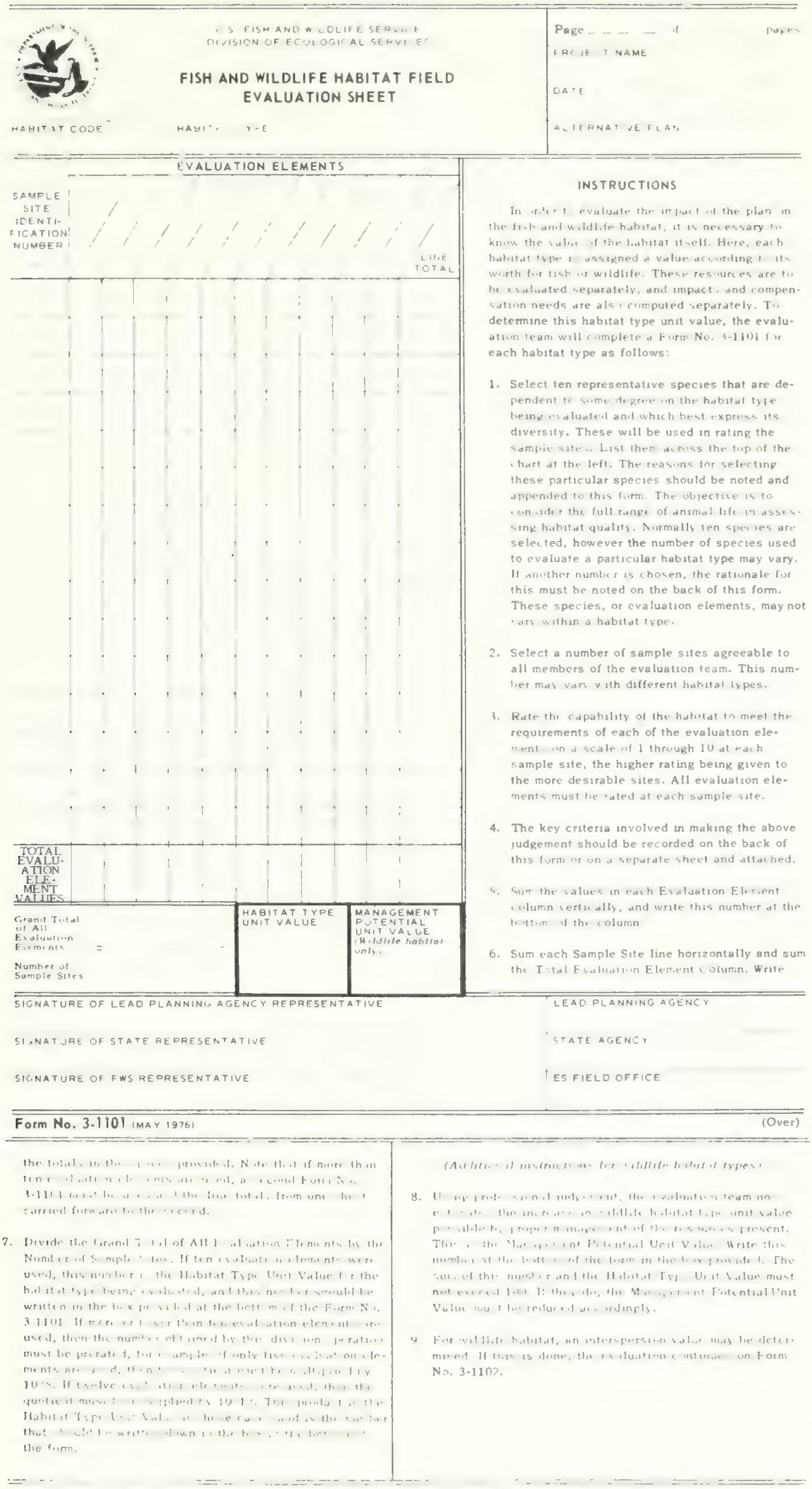
Detailed methodologies for assessing the effects of forest management on wildlife habitat, such as that presented by Thomas et al. (1976) and U.S. Forest Service and Missouri Department of Conservation (1976), are similarly impressive in their detailed ability to deal with the forest ecosystem. These forest evaluation systems deal mainly with harvestable components of forests that contain few plant and animal species. The vegetative responses in these components are generally known and the areas affected are clearly defined. Even with these advantages considerable field time, data collection, analysis, and interpretation are required to make useful predictions.

The procedure we have worked with most intimately is the Habitat Evaluation Procedures reported on elsewhere in this symposium by Adrian Farmer. In 1976, the HEP system was developed by the Division of Ecological Services in the Fish and Wildlife Service. The Missouri System (Daniel and Lamaire 1974) served as the basis for HEP. Using HEP, habitat types are evaluated for certain animals that are chosen to best represent the diversity of the types. The capability of the vegetative types to meet requirements of each of the animals is rated on a 1 through 10 scale, the higher rating being given to the more desirable sites. HEP Field Form 3-1101 (Figure 3) is used to record the site evaluations. Key criteria are being developed to aid in this evaluatory process. The Missouri Handbook (Flood et al. 1977) is a prototype set of key criteria written only to evaluate vegetative types for Missouri game animals. Work is currently underway to develop key habitat evaluation criteria for non-game species in Missouri. Presently, modifications of line charts (Whitaker et al. 1976) and the concepts used in the Missouri Handbook (Flood et al. 1977) are being combined to produce a modified set of evaluation criteria for potential use with HEP.

THE COMMON CONCEPTUAL BASE OF MOST METHODS

The various currently active methods of evaluating wildlife habitats have certain things in common. Methods being developed by the Corps of Engineers, Soil Conservation Service, and Ecological Services in conjunction with the State conservation agencies, are all based on assessments of habitat from the standpoint of the needs of the animal. They are based on a very simple premise that all animals need food, water, and cover, and some have special reproductive requirements. While these may seem to be very simple categories that embody a large array of complex biological concepts, they are defendable general categories (critical parameters) from which to begin assessments.

Food and water provide obvious physiological needs which must be met for survival of the individual animal, and thus the reproducing population. We know that white-tailed deer browse on the growing shoots of plants in early stages of succession, and later in succession can utilize mast produced by the mature plants. We know from examination of the literature that we would probably have more deer if we had both successional situations, and that in certain circumstances the distance to water may be a critical factor. While this is a very basic consideration of what can become a complex topic, we maintain that this approach can be used for every animal regardless of the complexity of its interactions with other animals and its habitat. If something has a highly specific food need, such as brant (*Branta bernicla*) feeding upon eelgrass (*Zostera marina*), we write evaluation characteristics with that specific need in mind. The specific nature of food needed in this case does not preclude the conclusion that, in their need for food and water, there is something quite similar between deer and brant.



U.S. FISH AND WILDLIFE SERVICE
DIVISION OF ECOLOGICAL SERVICES

FISH AND WILDLIFE HABITAT FIELD EVALUATION SHEET

Page ____ of ____ pages

PROJECT NAME

DATE

ALTERNATIVE PLAN

HABITAT CODE

HABITAT TYPE

EVALUATION ELEMENTS

SAMPLE SITE IDENTIFICATION NUMBER

LINE TOTAL

TOTAL EVALUATION ELEMENT VALUES

Grand Total of All Evaluation Elements
Number of Sample Sites =

HABITAT TYPE UNIT VALUE

MANAGEMENT POTENTIAL UNIT VALUE (Wildlife habitat only)

INSTRUCTIONS

In order to evaluate the impact of the plan on the fish and wildlife habitat, it is necessary to know the value of the habitat itself. Here, each habitat type is assigned a value according to its worth for fish or wildlife. These resources are to be evaluated separately, and impacts and compensation needs are also computed separately. To determine this habitat type unit value, the evaluation team will complete a Form No. 3-1101 for each habitat type as follows:

1. Select ten representative species that are dependent to some degree on the habitat type being evaluated and which best express its diversity. These will be used in rating the sample sites. List them across the top of the chart at the left. The reasons for selecting these particular species should be noted and appended to this form. The objective is to consider the full range of animal life in assessing habitat quality. Normally ten species are selected, however the number of species used to evaluate a particular habitat type may vary. If another number is chosen, the rationale for this must be noted on the back of this form. These species, or evaluation elements, may not vary within a habitat type.

2. Select a number of sample sites agreeable to all members of the evaluation team. This number may vary with different habitat types.

3. Rate the capability of the habitat to meet the requirements of each of the evaluation elements on a scale of 1 through 10 at each sample site, the higher rating being given to the more desirable sites. All evaluation elements must be rated at each sample site.

4. The key criteria involved in making the above judgement should be recorded on the back of this form or on a separate sheet and attached.

5. Sum the values in each Evaluation Element column vertically, and write this number at the bottom of the column.

6. Sum each Sample Site line horizontally and sum the Total Evaluation Element Column. Write the totals in the space provided. Note that if more than ten evaluation elements are used, a second Form No. 3-1101 must be used and the line totals from one sheet carried forward to the second.

7. Divide the Grand Total of All Evaluation Elements by the Number of Sample Sites. If ten evaluation elements were used, this number is the Habitat Type Unit Value for the habitat type being evaluated, and this number should be written in the box provided at the bottom of the Form No. 3-1101. If more or fewer than ten evaluation elements were used, then the number obtained by this division operation must be prorated, for example, if only five evaluation elements are used, then the quotient must be multiplied by 10/5. If twelve evaluation elements were used, then the quotient must be multiplied by 10/12. The product is the Habitat Type Unit Value in these cases and is the number that should be written down in the box at the bottom of the form.

SIGNATURE OF LEAD PLANNING AGENCY REPRESENTATIVE

LEAD PLANNING AGENCY

SIGNATURE OF STATE REPRESENTATIVE

STATE AGENCY

SIGNATURE OF FWS REPRESENTATIVE

ES FIELD OFFICE

Form No. 3-1101 (MAY 1976)

(Over)

(Additional instructions for wildlife habitat types)

8. Using professional judgement, the evaluation team now estimates the increase in wildlife habitat type unit value possible by proper management of the resources present. This is the Management Potential Unit Value. Write this number at the bottom of the form in the box provided. The sum of this number and the Habitat Type Unit Value must not exceed 100. If they do, the Management Potential Unit Value must be reduced accordingly.

9. For wildlife habitat, an interspersion value may be determined. If this is done, the evaluation continues on Form No. 3-1102.

Figure 3. Habitat Evaluation Procedures Field Form 3-1101 on which values are placed for species from different sites of the same habitat type (U.S. Fish and Wildlife Service 1976).

Cover is a very loose term that includes potentially just about everything about habitat that is not incorporated under the category of food and water. Protection from weather and enemies are the most obvious functions of cover for the animal, and extend into the special reproductive requirements of some species. We know, for example, that in northern states ruffed grouse (Bonasa umbellus) utilize aspen (Populus tremuloides) buds to get them through the winter and that several stages of succession in aspen are necessary for good ruffed grouse habitat. Dense cover in early stages of aspen and other vegetation provides not only food, but protection for broods during critical summer periods. An example of a difficult habitat characteristic to quantify is the special need by prairie chickens (Tympanuchus cupido) and sharp-tailed grouse (Pedioecetes phasianellus) for open space at their communal breeding sites. Again, while we can go very deeply into the complexities of such needs for an array of animals, they can be categorized in a useful fashion and certainly can be dealt with in detail in the construction of sets of criteria for application at a particular site.

Successional stages, in addition to distribution and abundance of plant species, are especially important when considering characteristics of habitat. Bulrush (Scirpus spp.) and cattail (Typhus spp.), occurring throughout a marsh in clumps, provide nesting and brood cover for waterfowl, but in later stages of succession these plants may choke the marsh and prevent utilization by young waterfowl. Therefore, not only can individual plant species prove important to animals, but also the seral stage within which they occur.

Some biologists seem to believe that diversity is a magic concept when applied to vegetation and wildlife habitat. It can be defined and measured in a variety of ways, and is currently incorporated into several of the habitat evaluation methods. Use of the word in these various methods involves value judgments which must be made with care. Diversity is not necessarily our goal in every case. For example, a species which is common in one area may be under pressure elsewhere due to habitat changes. We might well be justified in sacrificing diversity of plants and animals on that one area to ensure perpetuation of the species in question.

Interspersion and edge effect are loosely defined terms related to the juxtaposition of vegetative types, and thus to provision of the multiple needs of most animals for a variety of habitat types. There is not much consolidated information on the real nature and effects of these factors on animal species and populations. There is abundant indirect information from movement studies, life history information from a variety of habitats, and even some direct information on the effects of manipulating the presence of a variety of habitat types for common animals, such as bobwhite quail (Colinus virginianus) or white-tailed deer. In general, however, we need to more clearly define, measure, and interpret how interspersion and edge really affect animals. Most of the habitat methodologies currently in use are attempting to deal with this question, and most biologists agree that it is one of the more important parameters, although nobody knows exactly how to handle it.

There is some controversy over the role that specific information about the presence of animals on a given site has as a critical parameter of wildlife habitat quality. This again involves a considerable value judgment, and for the present, HEP is approaching this from the standpoint that it is the potential of the habitat that is important, based on interpretation of the identified characteristics of the habitat that affect animal presence, rather than whether or not the animal is actually present. Too many human interferences may affect animal presence, even when a given piece of land has considerable potential for production of wildlife.

Based on our experience with work in Missouri related to HEP Handbook development and our review of other existing methods, the general categories of food and water, cover, and special reproductive requirements are the only generally applicable "critical parameters of wildlife habitat" that we are capable of defining at this stage. Careful evaluation of what we really need to know to judge habitat indicates that we can work within this broad framework to provide a useful methodology. There is no scientific justification for designing more sensitivity into our system than is warranted by the quality and quantity of the data and eventual output of the evaluation system. Where more information is available, as in forests and the developing literature on bird species in relation to habitat, then more detailed and rigorous criteria may be developed and used in the field.

DEVELOPMENT OF HEP PROTOTYPE (MISSOURI) HANDBOOK

BACKGROUND

For 3 years the Missouri Cooperative Wildlife Research Unit has been working to standardize field evaluations of terrestrial wildlife habitats using HEP by means of a handbook containing evaluation guidelines. Details on the development of the Missouri Handbook (Flood et al. 1977) are useful in illustrating the use of existing information from diverse sources to help standardize field evaluations. Bettina Flood Sparrowe conducted the primary research project, with guidance from the senior author of this paper, and from Thomas S. Baskett, Leader of the Missouri Cooperative Wildlife Research Unit, Joseph P. Bachant, Clarence Daniel, John B. Lewis, and other biologists with the Missouri Department of Conservation, biologists with the St. Louis District Army Corps of Engineers, and the Kansas City Area Office of the Fish and Wildlife Service. Mimi Sangster, Research Specialist with the Missouri Unit, significantly aided in rewriting and polishing the final draft, as did other Unit staff members and students.

The primary objective of the Missouri study was to develop for HEP a measurable, standard set of habitat characteristics for use as a handbook during habitat evaluations. Our basic premise was that, regardless of the methodology employed in the field, there must be a display of the habitat characteristics which are evaluated. Our task was to provide a prototype handbook which illustrated how literature and other information sources could provide criteria for measuring the capability of a habitat at a development site to support a species or group of species. We felt a handbook should systematize the approach to field evaluations on water resource project sites and reduce the time spent in the field developing evaluation guidelines. Written criteria, based on solid biological facts about habitat needs of animals, should make evaluations and resulting scores less subjective and variable.

PREPARATION OF HANDBOOK

The proposed Meramec Park Lake site in Crawford county, eastern Missouri, was chosen as the primary project study area. We felt that insight could be gained into problems involved in using HEP, through tests with a handbook at an actual water resource project area. A secondary area of study was the University of Missouri's Ashland Wildlife Area in southern Boone county, central Missouri.

Ideas and guidelines for developing the handbook were derived from an early developmental phase of HEP. Few guidelines were given for handbook preparation, except for a proposed list of nine animal groups or Evaluation Elements.

The Meramec Park Lake EIS (Corps of Engineers 1973) was used to identify, as Evaluation Elements, those animals which occurred most commonly and reproduced successfully in the area. The numbers of species from the EIS that fell under the original Evaluation Element titles ranged from 1 under "Forest Game" to 66 "Other Birds" (songbirds). The Evaluation Element groupings as they appear in the Missouri handbook are: (1) Forest Game--white-tailed deer and wild turkey (*Meleagris gallopavo*); (2) Upland Game--bobwhite quail, eastern cottontail rabbit (*Sylvilagus floridanus*), and woodchuck (*Marmota monax*); (3) Tree Squirrels--eastern fox squirrel (*Sciurus niger*) and eastern gray squirrel (*Sciurus carolinensis*); (4) Terrestrial Furbearers--raccoon (*Procyon lotor*), opossum (*Didelphis marsupialis*), striped skunk (*Mephitis mephitis*), red fox (*Vulpes vulpes*), and gray fox (*Vulpes cinereoargenteus*); (5) Aquatic Furbearers--muskrat (*Ondatra zibethicus*) and beaver (*Castor canadensis*); and (6) Waterfowl--wood duck (*Aix sponsa*) and hooded merganser (*Lophodytes cucullatus*).

The EIS was also used to identify the habitat types of the area. These were vegetative types that could be readily identified from aerial photographs. Six types were included in the Handbook: Bottomland Hardwood, Upland Hardwood, Old Field, Pasture, Small Grain and Row Crops, and River/Riverine.

The next step in handbook preparation was to determine, from the literature, habitat needs for each group of animals in each habitat type. It was impossible to choose 1 species to represent a group of 66 species, so representative animals that were found to have similar habitat requirements were grouped as Evaluation Elements. Criteria (habitat characteristics) were then written for the group of animals. If an animal in the group had a specific requirement that could be very limiting (e.g., brant and eel grass), it was given more emphasis in constructing the habitat characteristic than the other species in the group with more general needs.

Food and water, cover, and reproductive needs were always the primary, broad categories for which habitat characteristics were written. After the first version of the handbook was prepared, it was sent to biologists with the Fish and Wildlife Service, Missouri Department of Conservation, Forest Service, Corps of Engineers, and University of Missouri-Columbia. After this review, the field form format was changed, but it remained constant through four more revisions and appears in the final published version (Flood et al. 1977). Field forms as they appear in the handbook are not meant to replace Field Form 3-1101 (Figure 3) from HEP (Fish and Wildlife Service 1976).

CONTENTS OF THE MISSOURI HANDBOOK

The Missouri Handbook (Flood et al. 1977) contains an introduction, glossary of terms, instructions for use, narratives and scoring outlines for six Evaluation Elements, and conclusions. Evaluation Element sections begin with a narrative that provides a synopsis of the habitat requirements of each animal group, including a literature review of the species' habitat requirements. A list of preferred plant and/or animal foods, a list of cavity-forming trees of relevance to the group, and a list of references follow the narrative. One field form per critical habitat is presented next, i.e., Forest Game involves five field forms, Tree Squirrels involves two field forms, etc.

The field form for Forest Game-Upland Hardwood is reproduced here (Figure 4) as an example. The habitat characteristics are written with food and water, cover, special reproductive requirements, etc., in mind. Three gradations of each characteristic are given as choices for scoring, relating to high, medium, and low indicators of habitat quality, as shown by the numbers following each phrase (Figure 4).

Certain habitat factors are more nearly limiting than others. In this handbook, factors most important to the animals can be scored up to 10, but less important factors range only to a maximum of 5 (Figure 4). Final scores are derived by multiplying the sums of weighted scores by 0.66 (Figure 4).

Scores from use of this or similar handbooks should be the bases of inputs for HEP Form 3-1101 (Figure 3). This handbook does not constitute a separate evaluation system, but contains principles and ideas which can provide a sound basis for the field evaluation portion of other habitat evaluation methods. Only slight modifications would be needed to adapt these evaluation criteria to other closely related ecoregions. Currently, students working through 10 Cooperative Wildlife Units are cooperating with Division of Ecological Services personnel to develop prototype handbooks for habitat types in other regions of the country following Bailey's (1976) "Ecoregions of the United States." Eventually, handbooks will be prepared for every ecoregion.

RESULTS OF FIELD TESTS

Field tests were held after peer review of the handbook. The tests were primarily run to refine the habitat characteristics and test the utility of the set of guidelines proposed for field evaluations. Because some changes were made in the handbook after each field test, the results are not directly comparable (i.e., the handbooks were not precisely the same). Field test results do indicate certain broad tendencies that are noteworthy.

Although three field tests were made, most comparisons between runs concern only the March (first handbook) and June (first revision of handbook) tests, since the July (second revision of the handbook) was on a different field site and used a very different handbook.

Two examinations of variation in scoring were made. By comparing ranges and standard deviations of scores for groups and individuals, we learned that groups show less variation in scoring than individuals (Table 1). A second look at score variation was accomplished by comparing scores for only the eight people that appeared in both the March and June tests. This was done to account for variation in scores due to different individuals making evaluations, and inexperience in using the handbook. Five percent of the scores were the same in March as in June, 34 percent of the March scores were higher, and 61 percent of the June scores were higher (Figure 5). Some of the higher scores in June were given for Upland Hardwood sites, but 64 percent of the higher scores in June were for Old Field sites. Higher June scores apparently reflected seasonally greater abundance of food and cover. A further discussion of seasonal differences in scoring appears later.

Evaluation Element: FOREST GAME   Habitat Type: BOTTOMLAND HARDWOOD

CHARACTERISTICS   POSSIBLE SCORE   ACTUAL SCORE*

I. Tree size class and canopy closure   I.__________

CODE

CANOPY CLOSURE
1 = 70-100%
2 = 40-69%
3 = 10-39%

SIZE CLASS OF 50% OR MORE OF STAND
S = sawtimber (9" and above dbh)
P = poles/small trees (2-8.9" dbh)
R = reproduction (less than 2" dbh)
NO SIZE CLASS MAKES UP 50% OF STAND
M = mixed

A)2-S	10
B)3-S	9
C)1-S	8
D)3-M	7
E)2-M	6
F)1-M	5
G)1-R; or 2-R; or 3-R	4
H)3-P	3
I)2-P	2
J)1-P	1

II. Preferred food plant diversity (consider only species in significant amounts)   II.__________

A)many species	8-10
B)some species	4- 7
C)few species	1- 3

III. Browse availability (vegetation up to 7')   III.__________

A)abundant	8-10
B)moderately abundant	4- 7
C)sparse	1- 3

IV. Vegetative cover (shrubs and herbs)   IV.__________

A)covers more than 50% of forest floor	8-10
B)covers 20-49% of forest floor	4- 7
C)covers less than 20% of forest floor	1- 3

V. Openings (less than 10% canopy closure)   V.__________

A)many	5
B)some	3- 4
C)few	1- 2

VI. External edge   VI.__________

A)meandering/dense vegetation	5
B)slightly meandering/moderately dense or discontinuous vegetation	3- 4
C)straight/sparse vegetation	1- 2

VII. Diversity of non-preferred plants (consider only species in significant amounts)   VII.__________

A)many species	5
B)some species	3-4
C)few species	1-2

*IF CHARACTERISTIC NOT APPLICABLE, ENTER NA AND DO NOT COUNT IT AS A CHARACTERISTIC USED

---

(1) Total scores I-IV..........................(1)___
(2) Number of CHARACTERISTICS used in (1)......(2)___
(3) (1) ÷ (2)..................................(3)___
(4) Total scores V-VII.........................(4)___
(5) Number of CHARACTERISTICS used in (4)......(5)___
(6) (4) ÷ (5)..................................(6)___
(7) (3) + (6)..................................(7)___
(8) (7) x 2 ÷ 3................................(8)___ HABITAT UNIT VALUE

Figure 4. Field form for Forest Game-Upland Hardwood which illustrates habitat characteristics, how they are used in scoring, and weighting of characteristics (Flood et al. 1977).

Table 1. Comparisons of Scoring Involving Eight Combinations of Evaluation Elements/Habitat Types/Areas at Meramec and Ashland Sites in March, June, and July, 1976

Test (Meramec or Ashland)	Individual or group	N	With or without[a] handbook	(1.0-10.0)	Mean	Standard deviation
March (M)	I	10	With	3.0-9.5	6.3	1.43
March (M)	G	4	With	4.0-8.6	6.5	1.08
June (M)	I	23	With	3.2-9.1	6.6	1.04
June (M)	G	7	With	3.5-8.5	6.5	0.99
July (A)	I	9	With	2.1-8.1	5.6	1.41
July (A)	I	9	Without	1.0-8.9	5.8	1.68
July (A)	G	3	With	3.2-7.5	5.6	1.24

[a] Use of HEP Form 3-1101 without written criteria.

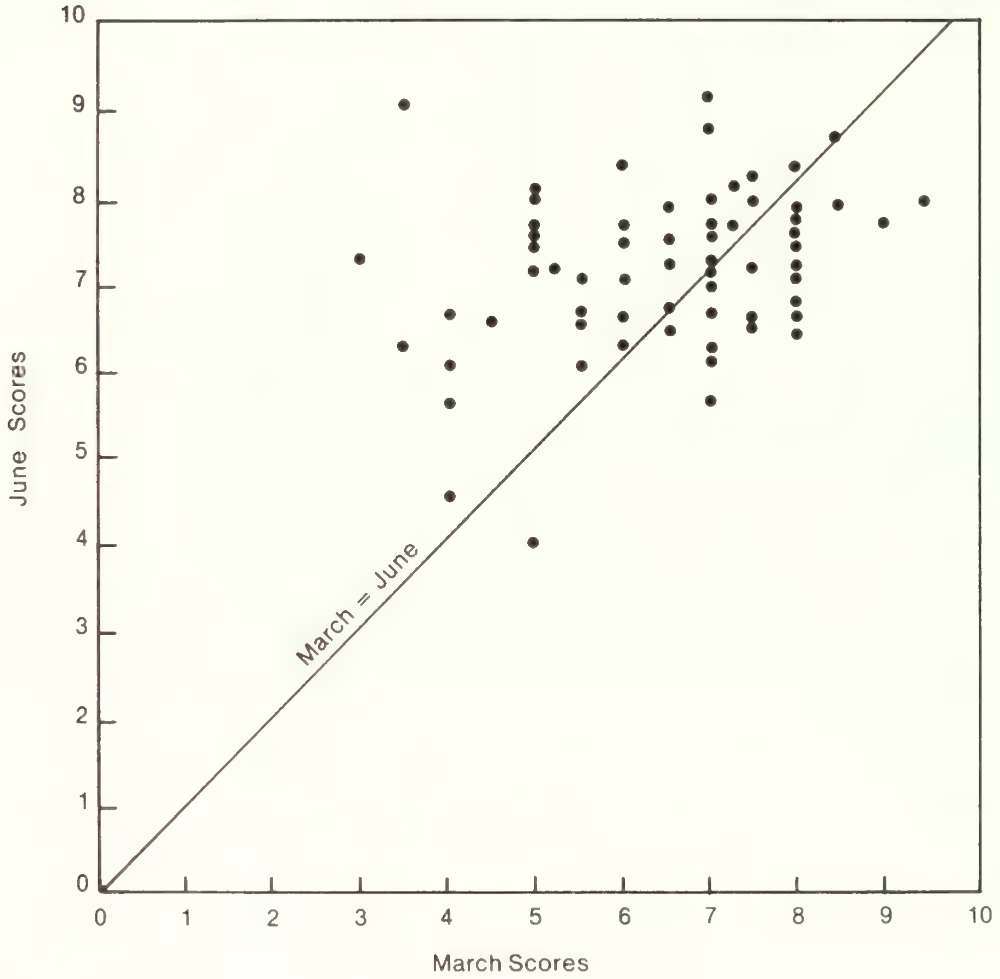


Figure 5. Mean scores for eight people on Meramec Areas I and II in March and June 1976. Eight combinations of animal group/habitat type/area were tested.

Nine people scored two sites on the Ashland Wildlife Area (secondary study area) in July (Table 1). The same nine people gave scores "with" and "without" the handbook on the same sites, scoring "without" first to avoid bias. Fifty percent of the comparisons showed significantly ($P<0.05$) more variation in scores "without" the handbook. A greater range of scores was also given "without" than "with" the handbook.

This preliminary test indicates that variation in scoring may be decreased with a handbook of criteria. The question that arises is whether standardization of scores promotes correct evaluation of sites or whether it simply compresses the range of values given. If knowledgeable biologists are employed for habitat evaluations, though, one can assume that their standardized scores will be reasonable measures of habitat quality.

To investigate the premise that groups score with the same tendencies as the individuals within them do, correlation coefficients were determined for scores of individuals and groups within the March and June field tests. Coefficients in March showed no trends in individual and group scoring, indicating many other sources of variation besides those variables designated. Much variation that was due to problems with the handbook, including instructions and terminology, was reduced in the June tests.

A relationship was apparent between Upland Game and Forest Game evaluation elements for both habitat types, both test areas, and both individual and group scores in June (Table 2). All coefficients for the June tests were positive, so a low or high score indicated the same scoring trend for the second animal group. This relationship between scores for animal groups with dissimilar habitat needs indicates a bias caused by wording or computations in the handbook. It may also indicate that observers score in the same manner (high or low) without regard for actual habitat conditions, or that an area judged of high quality for one animal group will automatically be judged in the same way for others. This has significance when the question of evaluating habitat for specific animals arises. Perhaps evaluating features of the environment (moisture availability, plant species diversity, type of management, etc.) for the composite faunal community would be more relevant and give truer scores.

In most cases individual scores were unaffected by the scores on a previous area (Table 2). Correlations of scores between habitat types on a test site showed independence of individual scoring. If the Old Field type were always scored high or low for Upland Game, a high degree of correlation between Old Field and Upland Game would be shown. Since coefficients of correlation were low, observers seemed to be evaluating the sites for their individual properties without bias toward higher scores in a particular habitat type.

For the March and June tests combined, evaluating forest habitat by averaging separate strata (ground, understory, and overstory) scores proved more variable than evaluating the forest holistically, with three strata combined. Averages-of-the-strata scores were lower than holistic scores 70 percent and 66 percent of the time in March and June, respectively. Observers were apparently more critical, showing lower scores, when evaluating the parts rather than the whole.

Numbers of plant species encountered and diversity indices for March and June were calculated (Table 3). Shannon's (1948) formula for diversity was used. The number of woody species did not substantially change, but herbaceous plants were much more prevalent in June than March. Species composition in the ground layer of forests and fields increased an average of 32 species in June.

Table 2. Correlation Coefficients Denoting Scoring Relationships of Test Areas, Habitat Types, and Evaluation Elements for Meramec Sites in March (Test 1) and June (Test 2), 1976

Combination[a]	Individual or group	Correlation elements[a]	Correlation Coefficients Test 1	Test 2
OF/AI	I	UG/FG	0.740[b]	0.598[b]
OF/AII	I	UG/FG	0.057	0.869[b]
UH/AI	I	UG/FG	0.182	0.707[b]
UH/AII	I	UG/FG	0.692	0.741[b]
OF/FG	I	AI/AII	0.317	0.422[b]
OF/UG	I	AI/AII	0.241	0.339
UH/FG	I	AI/AII	0.165	0.054
UH/UG	I	AI/AII	0.073	0.389
FG/AI	I	OF/UH	0.159	0.208
FG/AII	I	OF/UH	0.300	0.326
UG/AI	I	OF/UH	0.074	0.312
UG/AII	I	OF/UH	0.094	0.616[b]
OF/AI	G	UG/FG	0.461	0.812[b]
OF/AII	G	UG/FG	0.781	0.966[b]
UH/AI	G	UG/FG	0.982[b]	0.403
UH/AII	G	UG/FG	0.091	0.836[b]
OF/FG	G	AI/AII	0.242	0.232
OF/UG	G	AI/AII	0.813[b]	0.442
UH/FG	G	AI/AII	0.891[b]	0.285
UH/UG	G	AI/AII	0.189	0.698[b]
FG/AI	G	OF/UH	0.786[b]	0.047
FG/AII	G	OF/UH	0.961[b]	0.190
UG/AI	G	OF/UH	0.484	0.029
UG/AII	G	OF/UH	0.760[b]	0.723[b]

[a] OF=Old Field,
UH=Upland Hardwood,
AI=Area 1,
AII=Area 2,
UG=Upland Game,
FG=Forest Game,

[b] PL < 0.05

Table 3. Species Abundance and Diversity Indices (Shannon 1948) for Woody and Herbaceous Vegetation on all Meramec Sites in March and June, 1976

Habitat Type	Area	Vegetative Type	March Number of Species	March Diversity Index (H')[a]	June Number of Species	June Diversity Index (H')
Upland Hardwood	I	Woody	37	4.05	49	3.83
Upland Hardwood	I	Herbaceous	8	0.86	46	3.73
Upland Hardwood	I	Combined	45	4.20	95	4.11
Old Field	I	Herbaceous	22	3.15	40	4.27
Upland Hardwood	II	Woody	32	3.21	41	3.41
Upland Hardwood	II	Herbaceous	17	2.60	48	4.50
Upland Hardwood	II	Combined	49	3.65	89	3.77
Old Field	II	Herbaceous	17	1.82	33	3.90

[a] H' was calculated by using relative plant frequencies.

Compared to studies conducted in similar plant communities, Braun (1950), Union Electric Company (1974), and Bazzaz (1975), data from our work in the Meramec region indicates high species diversity for all habitat types. Diversity, in terms of species richness (abundance) and distribution increased from March to June in both habitat types.

Kulczynski's formula (Oosting 1956) was used to calculate coefficient of similarity values for like habitat types (Table 4). Percentages of similarity were higher for forests than fields. Both forest sites were similar in March and June, and degree of similarity was high from March to June for any one site. Little similarity was apparent for fields. As species richness increased from March to June, similarity coefficients decreased between the two sites.

Since habitat types may be very different between seasons, as shown by the diversity indices and similarity coefficients, scores based on field work in different seasons may not be similar enough to be validly compared.

CONCLUSIONS

There are various levels of organization from which we may approach assessments of habitat. We may classify things, that is, arrange and order them based on certain of their characteristics. We may inventory them, which assumes the existence of a classification system, whereby we may look at a region or the entire country to see what we have. We may analyze habitat, usually in the traditional sense of measurement of vegetation and the presence of animals. Finally, as a form of analysis, we may evaluate habitat, with regard to providing some kind of index to value of not only what exists on a plot of land, but what might be there over time. This must be done for purposes of making the unhappy, but necessary, trade offs with development of other natural resources.

We are making an appeal to set aside the academic arguments that say we need too much information; animals and their habitats are too different and we cannot evaluate habitats on a broad basis. Likewise we will not accept the argument presented by some field biologists that they have too many constraints upon them, that assessments of habitat are too rigorous and complicated with a written set of guidelines, or that they have too much to do in the time allotted. To solve these problems, persons on both sides of this issue need to reappraise reasons for which habitat assessments are being done. We need a clear statement of goals and objectives for whatever type of methodology is being presented, so that we may achieve an appropriate compromise between research scientists and field biologists.

Using readily available literature and commonly occurring animals provides a means of testing development of methodologies. Critical parameters of wildlife habitat were identified and used in such a test in Missouri. Preliminary results of field testing of the Missouri Handbook, a set of carefully developed criteria, showed that a handbook can save field time, standardize scores, and decrease variation in scoring. Many more tests are planned and further analyses of habitat evaluations must be done to delve into the detailed aspects of habitat characteristics used in the field. There is great promise in this approach to standardize judgment-based evaluations of wildlife habitat in the field.

Table 4. Similarity Coefficients of Vegetation Within and Between March and June, 1976, for Two Sites of Two Habitat Types on the Meramec Study Area

Site/area/season[a]	Similarity coefficient %
UH/I/March-UH/II/March	55
UH/I/June-UH/II/June	62
UH/I/March-UH/I/June	54
UH/II/March-UH/II/June	48
OF/I/March-OF/II/March	49
OF/I/June-OF/II/June	23
OF/I/March-OF/I/June	31
OF/II/March-OF/II/June	27

[a] UH = Upland Hardwood
OF = Old Field
I = Area 1
II = Area 2

LITERATURE CITED

Bailey, R.G. 1976. Ecoregions of the United States. U.S. For. Serv., Intermountain Region, Ogden, Utah.

Bazzaz, R.A. 1975. Plant species diversity in old-field successional ecosystems in southern Illinois. Ecology 56(2):485-488.

Braun, E.L. 1950. Deciduous Forests of Eastern North America. The Blakiston Co., Philadelphia, Pennsylvania. 596 pp.

Daniel, C., and R. Lamaire. 1974. Evaluating effects of water resource developments on wildlife habitat. Wildl. Soc. Bull. 2(3):114-118.

Dee, N., J.K. Baker, N.L. Drobny, K. Duke, and D.C. Fahringer. 1972. Environmental Evaluation System for Water Resource Planning. Battelle, Columbus Laboratories, Columbus, Ohio. 188 pp.

Flood, B.S., M.E. Sangster, R.D. Sparrowe, and T.S. Baskett. 1977. A Handbook for Habitat Evaluation Procedures. U.S. Fish and Wildl. Serv. Resour. Publ. 132. 77 pp.

Graber, J.W., and R.R. Graber. 1976. Environmental Evaluations Using Birds and their Habitats. Illinois Nat. Hist. Surv. Biol. Notes 97, Urbana, Illinois. 39 pp.

Hamor, W.H. 1970. Guide for Evaluating the Impact of Water and Related Land Resource Development Projects on Fish and Wildlife Habitat. USDA Soil Conserv. Serv., Lincoln, Nebraska. 25 pp.

Oosting, H.J. 1956. The Study of Plant Communities. W.H. Freeman and Company, San Francisco, California. 440 pp.

Shannon, C.E. 1948. A mathematical theory of communication. Bell Syst. Tech. J. 27:379-423, 623-656.

Thomas, J.W., R.J. Miller, H. Black, J.E. Rodiek, and C. Maser. 1976. Guidelines for maintaining and enhancing wildlife habitat in forest management in the Blue Mountains of Oregon and Washington. Trans. N. Am. Wildl. and Nat. Resour. Conf. 41:452-476.

Union Electric Company. 1974. Callaway Plant Units 1 and 2 Preconstruction Environmental Monitoring Annual Summary. Missouri Acad. Sci. Occas. Paper 4, Columbia, Missouri. 140 pp.

U.S. Army Corps of Engineers. 1973. Final Environmental Impact Statement for Meramec Park Lake. 338 pp.

________________. 1976. A tentative habitat evaluation system (HES) for water resources planning. Lower Mississippi Valley Div., Vicksburg, Mississippi. 76 pp.

U.S. Fish and Wildlife Service. 1976. Habitat Evaluation Procedures. Division of Ecological Services. Washington, D.C. 30 pp.

U.S. Forest Service and Missouri Department of Conservation. 1976. Program Evaluation...Wildlife Habitat Management. 40 pp.

Whitaker, G.A., and R.H. McCuen. 1976. A proposed methodology for assessing the quality of wildlife habitat. Ecological Modelling 2:251-272.

______________, E.R. Roach, and R.H. McCuen. 1976. Inventorying habitats and rating their value for wildlife species. Proc. Southeastern Assoc. Game and Fish Commissioners 30:(at press).

THE HABITAT EVALUATION PROCEDURES

Adrian H. Farmer
Project Impact Evaluation
U.S. Fish and Wildlife Service
Suite 11, One Drake Park
333 West Drake Road
Fort Collins, Colorado 80521

Abstract: The U.S. Fish and Wildlife Service has developed and implemented a wildlife habitat assessment procedure for use in water resource planning. This procedure is based on the assumption that the value of habitat for selected wildlife species can be accurately rated (on an index scale) by a team of biologists. The procedure also provides a mechanism for estimation of compensation requirements for habitat losses associated with a water development project.

INTRODUCTION

In recent years, emphasis has been placed on the development of ecosystem "models" or systematic analytical techniques which, through abstraction and simplification of the real world, provide a handy tool for assessing or predicting the outcome of land use changes. The purpose of this presentation is to describe this technique developed by the Division of Ecological Services, U.S. Fish and Wildlife Service.

This technique, called the Habitat Evaluation Procedures (HEP), was developed to provide a uniform, nationwide method of evaluating the impacts of water resource projects on fish and wildlife habitat. Moreover, the procedures are intended to generate analyses in accordance with the requirements of Federal legislation and planning guidelines, including the Fish and Wildlife Coordination Act, the National Environmental Policy Act of 1969, and the Principles and Standards for Planning Water and Related Land Resources (Pursuant to the Water Resources Planning Act of 1965).

The Fish and Wildlife Coordination Act requires that the appropriate state game and fish agency and the Fish and Wildlife Service be consulted by any Federal agency proposing to construct or license any modification of streams or other bodies of water ". . . with a view to the conservation of wildlife resources as well as providing for the development and improvement thereof in connection with such water resource development." In general, studies performed during consultation under the Fish and Wildlife Coordination Act involve preproject habitat inventories and alternative project evaluations, including recommendations for mitigation of losses or enhancement of fish and wildlife habitat.

The National Environmental Policy Act of 1969 requires full public disclosure of the environmental impacts of major Federal actions which significantly affect man's environment and requires that such information be arrayed in a decisionmaking format (environmental impact statement). An important aspect of the National Environmental Policy Act is the requirement for analysis and comparison of alternatives to a proposed action.

The Principles and Standards for Planning Water and Related Land Resources, implemented by the U.S. Water Resources Council in October 1973 (Federal Register, Vol. 38 [174] 10 September 1973), recognizes coequal water resource planning objectives of national economic development and environmental quality. Furthermore, the Principles and Standards requires that all alternative project plans be evaluated against both objectives and ". . . planning for the use of water and land resources in terms of these objectives will aid identifying alternative courses of action and will provide the type of information needed to improve the public decisionmaking process . . . ."

The Habitat Evaluation Procedures must therefore be capable of providing accurate project impact analyses including documentation sufficient to justify mitigation or enhancement measures. Additionally, HEP must be useful to quantitatively compare alternative project plans against the fish and wildlife components of two planning objectives (Environmental Quality and National Economic Development), in such a manner as to be readily understandable to a decisionmaker.

Fulfilling these requirements at present requires that the Habitat Evaluation Procedures employ both monetary and nonmonetary evaluations. However, since the monetary portion of the procedures is essentially the widely familiar man-day/recreation-day value approach, this paper will deal with the nonmonetary portion only.

HISTORICAL BACKGROUND

Acting upon the recommendation of the National Coordinating Committee for fish and wildlife conservation in water development programs (a formal committee consisting of representatives from state fish and game agencies, private conservation groups, and the Fish and Wildlife Service that meets annually to further national fish and wildlife programs) the Fish and Wildlife Service initiated efforts in 1973 to develop a nonmonetary evaluation system. Specific recommendations of the committee were:

(1) the evaluation system should be "community" oriented, i.e., must address habitat values for more than just harvestable species that lend themselves to economic valuation;

(2) to achieve an acceptable degree of resolution and sensitivity, the evaluation system must be capable of site specific design and calibration; and

(3) the system must be made available to the environmental community for review and opportunity should be afforded for appropriate feedback so the system can be progressively improved.

The initial development of a system was assigned to a task force of 13 individual representatives of state and Federal wildlife agencies and private conservation organizations. Upon reviewing existing methodologies, the group agreed that the system used by the State of Missouri (Daniel and Lamaire, 1974) encompassed the necessary concepts and was adaptable enough to meet national requirements for a standardized evaluation system. The Missouri system was incorporated as the nucleus of the new procedures which were entitled the Ecological Planning and Evaluation Procedures (EPEP). A trial application of the EPEP was conducted on a reservoir project in Kansas during 1974, and subsequently (November 1974), the EPEP were published and made available to the regions of the Fish and Wildlife Service, state game and fish agencies, and the major Federal construction agencies.

As a result of field applications on roughly 20 projects from November 1974 to March 1976, and the reviews of the EPEP by the environmental community, several problems were uncovered, not the least of which was the difficulty in understanding the procedures. HEP, a more concise version of the procedures published in 1976, incorporated several analytical modifications suggested by numerous field personnel and other reviewers.

PROCEDURES

BASIC ASSUMPTIONS

Habitat Evaluation Procedures are designed to assess three general parameters:

1. Habitat quality
    a. Actual
    b. Potential
2. Habitat quantity
3. Temporal changes in land use as they affect habitat quality and quantity.

Moreover, HEP makes certain assumptions about the assessment of those parameters, and their relationships to each other. These are:

1. Habitat Quality

Based on an assessment of habitat components or charateristics, a number from 0-10 can be assigned as proportional to the carrying capacity for a selected wildlife species on a unit area basis. (Measured in habitat units/area.)

2. Habitat Unit Value

The value of a unit area of habitat (vegetative association, major plant community, etc.) is the sum of the habitat quality indexes for all wildlife species evaluated. (Measured in habitat units/area.)

3. Habitat Value

The value of a segment of habitat (vegetative association, etc.) can be expressed as the product of the size of the segment and the habitat unit value (quality x quantity or habitat units/area x area).

Given that these assumptions are valid and that the same faunal groups are evaluated, HEP provides the capability to perform relatively sensitive site specific analyses to quantitatively compare projects at different sites and to estimate compensation requirements which might be satisfied at a location removed from the project site.

APPLICATION OF PROCEDURES

A necessary prerequisite to application of the procedures is the acquisition of aerial photography of the study area with sufficient resolution for delineation of habitat types. In practice, the delineation of habitat types is generally performed on the basis of vegetative composition which may include climatic or edaphic types or various successional stages. Although required, the delineation of habitat types could include physiographic features such as slope, aspect, etc. The objective of this habitat typing is the segmentation of the study area into relatively homogeneous units. The number of units or degree of resolution is dictated by the ability to recognize and ascribe uniquely different wildlife habitat values. For example, a project area in the southeast may contain numerous timber stands with widely differing compositions of hardwoods and pine; however, an observer may be able to recognize only two distinct classes (i.e., less than 50 percent pine and more than 50 percent pine) as having significantly different wildlife values.

After completion of a habitat map it is necessary to break the project-affected area into segments based on the type or degree of impact. The objective is to segment the area into relatively homogeneous units (based on land use change). Both directly affected areas and peripheral areas (indirectly affected) impacted by construction or operation of the project are considered. For example, the segments identified for a flood control reservoir might include the conservation pool, flood pool, lands purchased around the reservoir, downstream riparian habitat, and offsite land use changes such as commercial or industrial development, relocated highways, etc. The project segments are then superimposed onto the habitat type map to complete a second-order segmentation of the project study area, primary by habitat type and secondary by project segment.

This two-order segmentation results in defining a set of "habitat-impact" units that greatly simplify analyses, since there is only one habitat type and one impact type in each unit. Figure 1 depicts a project area containing three habitat types, each of which occurs in two project segments for a total of six habitat-impact units to be evaluated.

The actual appraisement of habitat unit values for each habitat type in the project is done by a team of biologists representing the construction agency, the state game and fish agency,and the Fish and Wildlife Service. Prior to performing any field work, the team must (1) select a representative number of sample sites in each habitat type, (2) decide upon a list of wildlife species to be considered during the field appraisement, and (3) establish rating criteria for each species in each habitat type.

At least three sample sites are selected in each habitat type, and depending on available time and manpower, the total number of samples that can be taken (4-10 per day on the average) is allocated proportionate to the predominance of each habitat type. Logistics [ease of access] are usually the controlling factors in selection of sample sites. Then, a sampling scheme, selective sampling or restricted random sampling, is used.

A concentrated effort is made by the team to give nongame species equal consideration when completing the list of species to be evaluated in each habitat type. Typically, this creates some confusion due to the large number of species involved, when compared to game species, and the diversity of habitat requirements, many of which are vaguely understood. The usual procedure is to aggregate several species into one "evaluation element," based on similarity of habitat requirements rather than on phylogenetic relationships. Examples of an evaluation element are canopy nesting insectivorous birds, small mammals, wading birds, etc. The rating criteria for each habitat type consists of a chosen set of habitat characteristics of importance for each species. Examples of characteristics considered are overstory age, overstory plant diversity, understory plant composition and density, ground cover (leaf litter, rocks, fallen logs), presence of grasses and forbs, denning sites, degree of grazing, soil moisture, and agricultural practices.

The appraisement of habitat type values entails the rating of each site, for each of the selected wildlife species, based upon the predetermined set of desirable characteristics. Ideally, for purposes of documentation, each pertinent characteristic should be rated, on a scale of 1-10, and averaged to provide a site value for each species. Moreover, the recording of individual characteristics provides an opportunity to obtain a site value "weighted" for the more important habitat characteristics for each species. In practice, however, the team members generally assign a site value for each species based on a subjective assessment and weighting of characteristic qualities. Each site value is obtained by summing the values for each wildlife species and the habitat unit value for each habitat type is obtained by averaging the site values.

The procedures allow for an adjustment of the mean habitat unit value for each habitat type by considering interspersion with other habitat types. The interspersion calculation is a relatively straightforward but extremely time-consuming process.

Basically, this process requires that a 40-acre (16.2 ha) square grid system be superimposed over the habitat map of the area. Then, individually for each habitat type, the grid cells that fall at least partially within the type are isolated. This set of grid cells is then subdivided into those that fall either wholly or partially within the habitat type. For each grid cell that falls only partially within the identified habitat type, the following calculations are performed:

1. The sum of the habitat unit values for all habitat types within the grid cell is calculated.

2. This sum is multiplied by 0.1 (the resulting product is limited to a maximum of 3 on the same scale of 1-10 by which each habitat type was previously rated).

3. The resulting product, from the above step, is added to the mean habitat unit value for the identified habitat type. This sum represents the adjusted value for only that acreage of the habitat type within the individual grid cell.

A weighted mean habitat unit value for each type is then obtained by multiplying the acreage of the habitat type within each grid cell (including the cells wholly within the habitat type) by the habitat unit value for the grid cell, summing all these products, and dividing by the total acreage of the habitat type. This weighted mean value represents the habitat unit value adjusted for interspersion.

After the field appraisement of habitat values and interspersion adjustments have been completed, the project impact analysis can be undertaken. The analysis is performed by individually considering each habitat-impact segment (Figure 1). The habitat within each segment has a preproject or "existing" value equal to the product of the habitat unit value (mean site value plus interspersion adjustment) and the acreage within the segment. It is necessary to consider the probable changes of the habitat value through time due to impacts in that project segment. For example, project segment 1 (Figure 1) might be a reservoir conservation pool that experienced 100 percent loss upon impoundment.

The habitat value-time projections are for the period of economic analysis used by the construction agency (usually 100 years). An annual average change in habitat value is calculated for each project segment and the results are combined to yield an average annual change for each habitat type. A summary of the project plan analysis is depicted in Table 1.

It is necessary to consider the possibility of some baseline condition, other than existing conditions, from which to calculate the average annual change in habitat value. The baseline is the "future without project" projections of habitat values or an estimate of future land use trends that would occur without project construction. For example, preproject land use trends and population projections might indicate a gradual increase in habitat values without the project. In such a case, changes in habitat values measured from existing conditions would underestimate the project impacts; just the opposite situation can also occur. This requires a large amount of "crystal balling," and owing to the gross uncertainties associated with 100-year projections, plus the fact that in many cases there are no available trend data, the existing conditions are generally assumed to represent the probable future conditions without the project. Figure 2 graphically displays both a baseline and project projection for a single habitat type. The area between the two projections, divided by 100 (period of analysis) yields the average annual change in habitat value attributable to the project.

The final phase of project evaluation entails the calculation of required compensation for habitat losses. HEP embraces the philosophy that habitat losses should be replaced in kind; i.e., a loss of riparian bottomland habitat, for example, must be compensated by similar gains in the same habitat type. Furthermore, compensation can only be acquired by increasing the value, through time, of a segment of land via acquisition and/or management. After a suitable tract of land is located, the habitat values are appraised as described above and the management potential for each habitat type is estimated. The difference between the management potential and the existing value for each habitat type defines the realizable gain from which comes compensation. A hypothetical example is given at the bottom of Figure 2. In this example, it is assumed that the maximum value of 10 HU/acre can be attained.

DISCUSSION

Habitat Evaluation Procedures have generally performed adequately judging from the responses of personnel within and outside the Fish and Wildlife Service. The procedures have successfully overcome many shortcomings of the

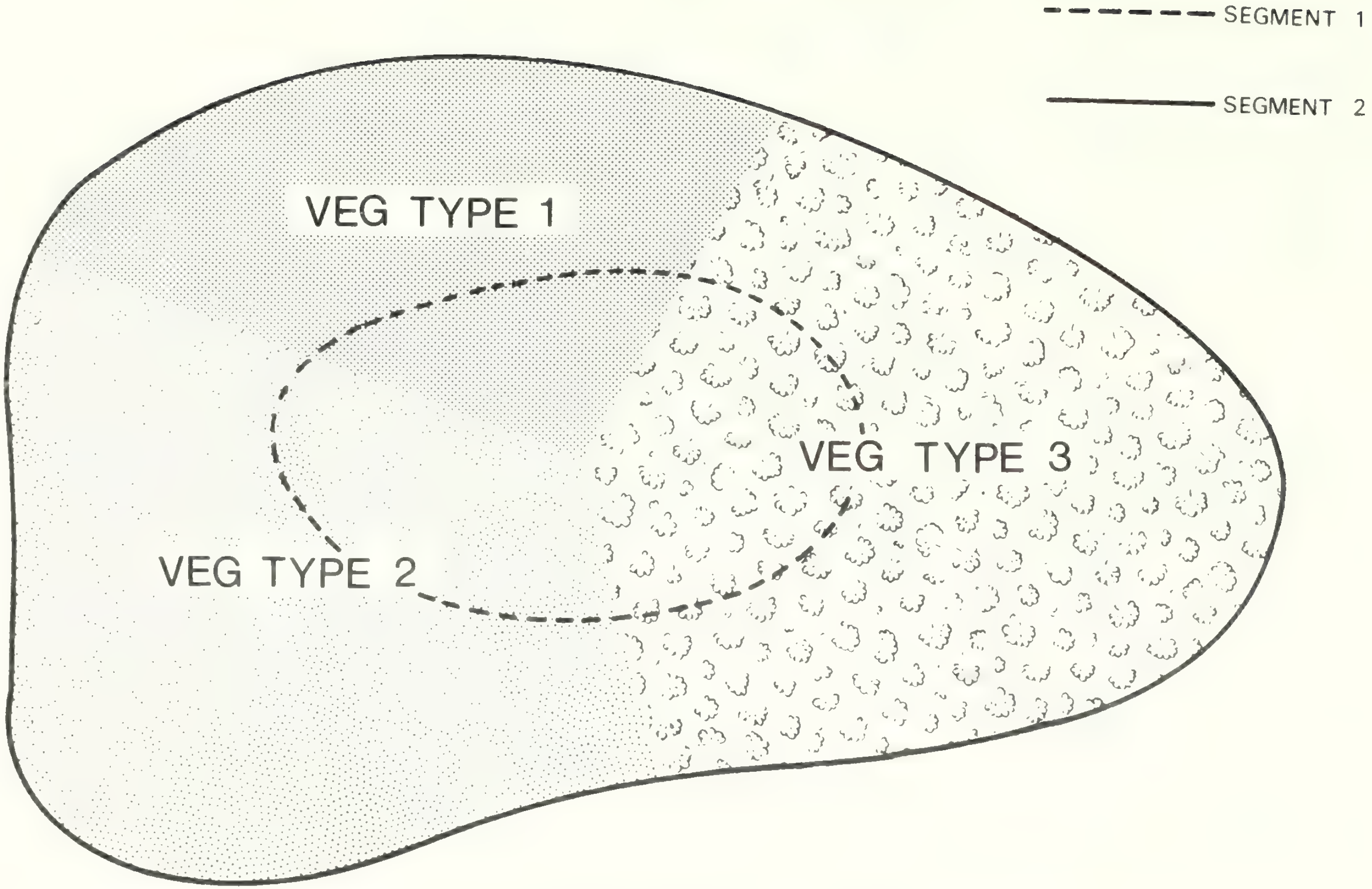
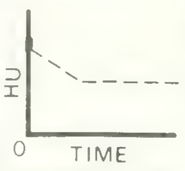
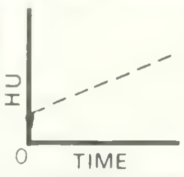
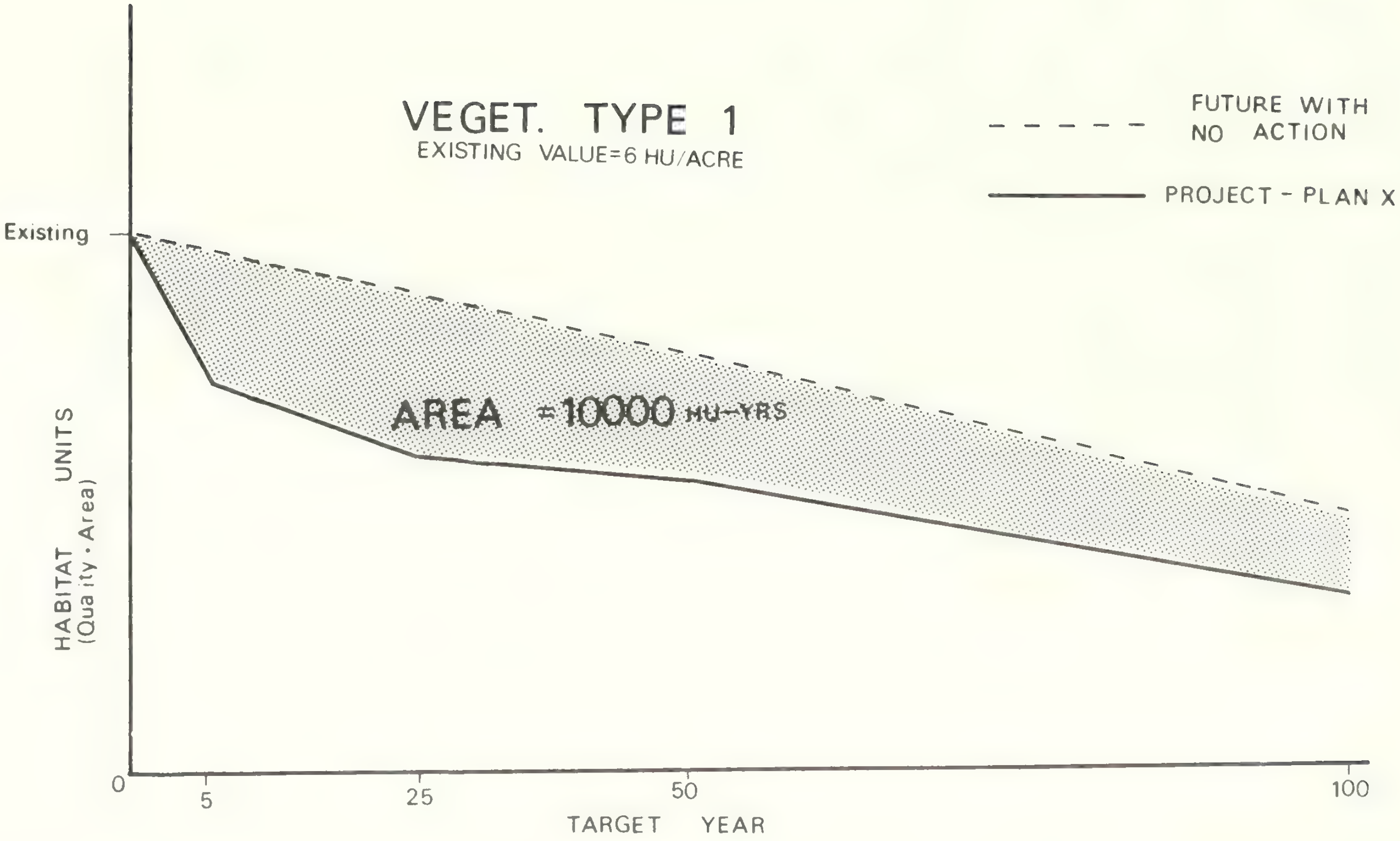


Figure 1. Segmentation of planning area showing vegetative associations and impact type or project segment.

Table 1. Summary of Project Plan Analysis (Non-monetary)

WILDLIFE SPECIES	A	B	C	D		E
VEGETATIVE ASSOCIATION (1)	TYPE 1 (Habitat Units/Acre)		TYPE 2		TYPE 3	
IMPACT SEGMENT (2)	1	2	1	2	1	2
AREA OF INVOLVEMENT	A(1,1)	A(1,2)	A(2,1)	A(2,2)	A(3,1)	A(3,2)
IMPACT-TIME RELATIONSHIP (Change in habitat value through time)						
AVERAGE ANNUAL IMPACT (100 YRS)	HU(±)	HU(±)				
TOTAL ANNUAL IMPACT (100 YRS) (Function of habitat quality, area, and time)	SUM -(Seg 1 & Seg 2)-Type 1		SUM - Type 2		SUM - Type 3	



$$\text{COMPENSATION} = \frac{\text{AVERAGE ANNUAL IMPACT}}{\text{MANAGEMENT POTENTIAL (HU/ACRE)}} = \frac{10000\,/\,100}{10-6} = 25 \text{ ACRES}$$

Figure 2. Future projections assuming project conditions and the alternative of no project. A hypothetical example is shown for calculating compensation requirements.

traditional man-day economic valuation which addresses only utilization of the resource, and ignores components of the ecosystem that have no documentable economic value to man. Moreover, the efforts required for application of the procedures are commensurate with the limited amounts of time and manpower available for water resource project evaluations. The procedures are simple enough in concept to be understood by technical and management level personnel, decisionmakers, and most laymen.

Many reviewers, however, have suggested that a major shortcoming of the procedures might be an inability to replicate results. Holmberg (1976), therefore, set out to test the replicability of the procedures, using analysis of variance (Kruskal-Wallace, "F" test). He employed at least two teams, each consisting of three observers, in several locations across the country. The teams independently rated chosen sites using predetermined rating criteria for the same wildlife species. Holmberg (1976) found that the habitat evaluations could be replicated, at the 95 percent level of confidence, if each team utilized the same rating criteria and team members had at least a basic understanding of the habitat requirements for the wildlife species evaluated.

A second potential problem with the HEP concerns the implicit assumption that habitat-unit-valve index scores are linearly proportional to productivity to the habitat. Figure 3 roughly depicts this problem by suggesting a non-linear relationship between habitat unit value index and "true" habitat value. As an example, consider that in Figure 3 a project results in the loss of 1 habitat unit/acre (from 1 to 0) for a given habitat type and this is compensated for by managing an equal sized segment of land from a value of 9 to 10. The corresponding increments of "true" habitat value are obviously quite different and, in this case, compensation will not be achieved. Considering the state-of-the-art, HEP are not unique with regards to imprecision. Nevertheless, well-thought-out rating crieria, for wildlife species about which habitat requirements are fairly well understood, are prerequisite to significant improvement. Consequently, the Fish and Wildlife Service has consummated a contract with the University of Missouri for the design of a "prototype" handbook to demonstrate the kinds of rating criteria best suited for the HEP applications.

Not unrelated to problems of precision is the need for other analytical improvements in the procedures, i.e., some efficient means of addressing interspersion and juxtaposition of habitat types. Most reviewers of HEP, including this author, believe that the 40-acre dot-grid approach requires an inordinate amount of time, considering the usefulness of the information gained. The dot-grid approach is summarized in Figure 4. As previously discussed, only the habitat contained in "edge-overlapping" grid cells is adjusted for interspersion. On the average, the edge-overlapping cells are bisected, consequently, "interspersion" values are applied only 660 feet (201 m) away from an edge. Additionally, a maximum of 3 units/acre (7.4 units/ha) (on the scale of 1-10) is all that can be attributed to interspersion no matter what wildlife species are identified in the evaluation. A more valid approach may be to use a different grid size and different range of interspersion values in evaluating each wildlife species. This greatly increases an already time-consuming approach. As an alternative digital data processing appears to offer the most potential in assessing interspersion parameters. At least one other habitat evaluation system in this subject area (Whitaker and McCuen, 1975) has utilized computer processing.

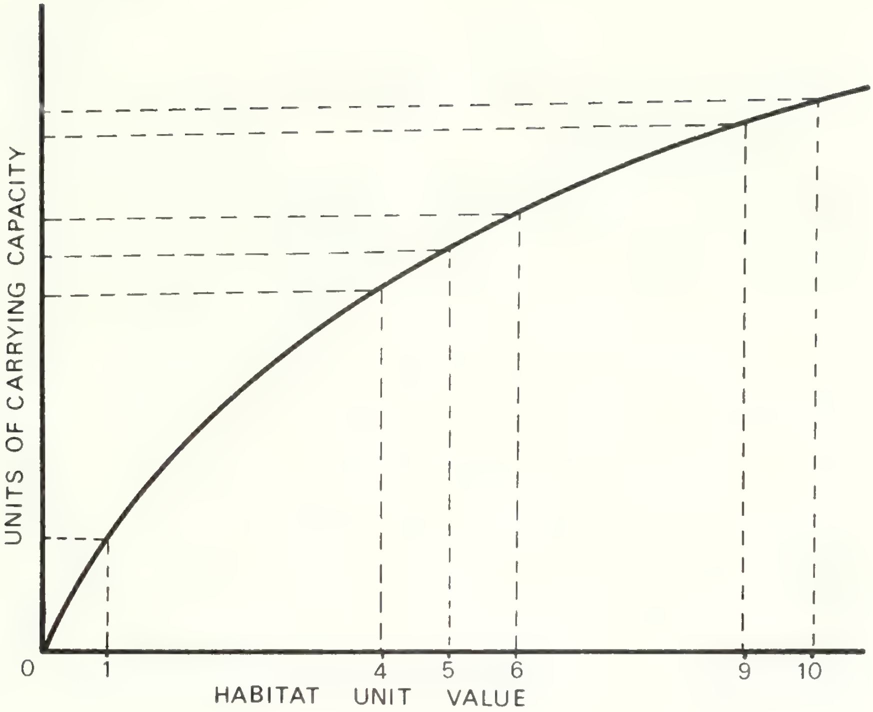


Figure 3. Hypothetical relationship between "true" habitat value and HU value index (noncalibrated model).

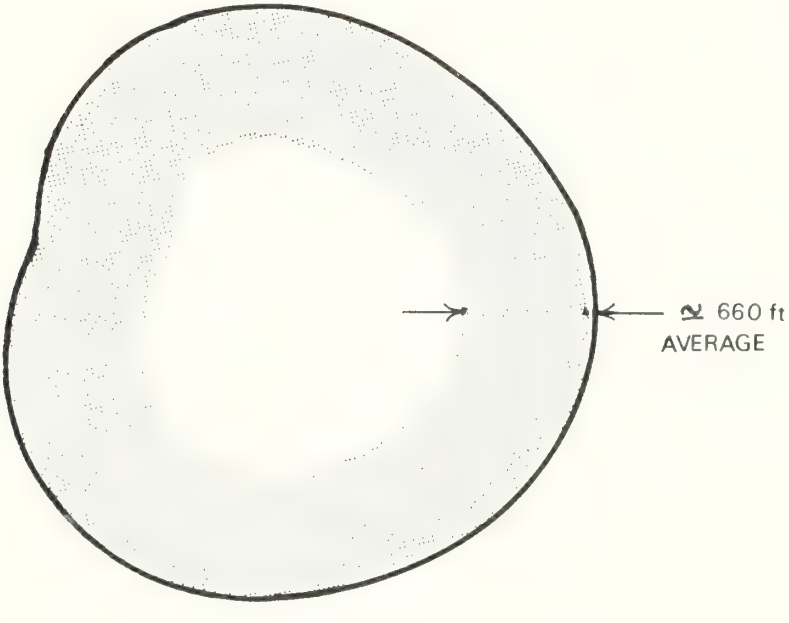


Figure 4. Continuous stand of habitat type. Shaded area is adjusted for interspersion.

Another analytical problem with HEP is the present method of calculating compensation requirements. The assumptions implied by HEP are that compensation through management will become fully effective at the outset and, furthermore, that the maximum possible habitat unit value (10) can be attained.

These assumptions make for conservative estimates because there is a time lag associated with the effectiveness of any management program. Furthermore, the validity of assuming that management can attain the maximum possible value of 10 is questionable since most biologists may have trouble visualizing ideal habitat conditions occurring at the same place and at the same time for all wildlife species used in the evaluation. The outcome of two differing sets of assumptions concerning compensation is shown in Figure 5. Many biologists would prefer being on the "conservative side" in view of other sources of imprecision.

SUMMARY

Although the Habitat Evaluation Procedures are far from being perfect, they provide the most objective tool presently available for assessing the effects of water resource development on fish and wildlife habitat. The U.S. Fish and Wildlife Service has identified the habitat evaluation efforts as a priority funding area in Fiscal Year 1977, established one biologist in each of its six regions, and is stationing a national team in Fort Collins, Colorado with the objective of providing a focal point, within the Service, for implantation of and technical refinements in the procedures. A requirement for the ultimate success of this effort will be the contribution of ideas, technical comments, and suggestions from other Federal and state agencies involved in water resource development.

LITERATURE CITED

Daniel, C. and R. Lamaire. 1974. Evaluating Effects of Water Resource Developments on Wildlife Habitat. Wildl. Soc. Bull. 2(3):114-118.

Holmberg, N.D. 1976. The Habitat Evaluation Procedures, Division of Ecological Services, U.S. Fish and Wildlife Service: A Test of Replicability. U.S. Dept. Interior, Fish and Wildlife Serv., Div. Ecological Serv., Washington, D.C. 14 pp.

Whitaker, E.A. and R.H. McCuen. 1975. A Proposed Methodology for Assessing the Quality of Wildlife Habitat. Tech. Rep. Dept. Civil Eng., Univ. Maryland, College Park, 31 pp.

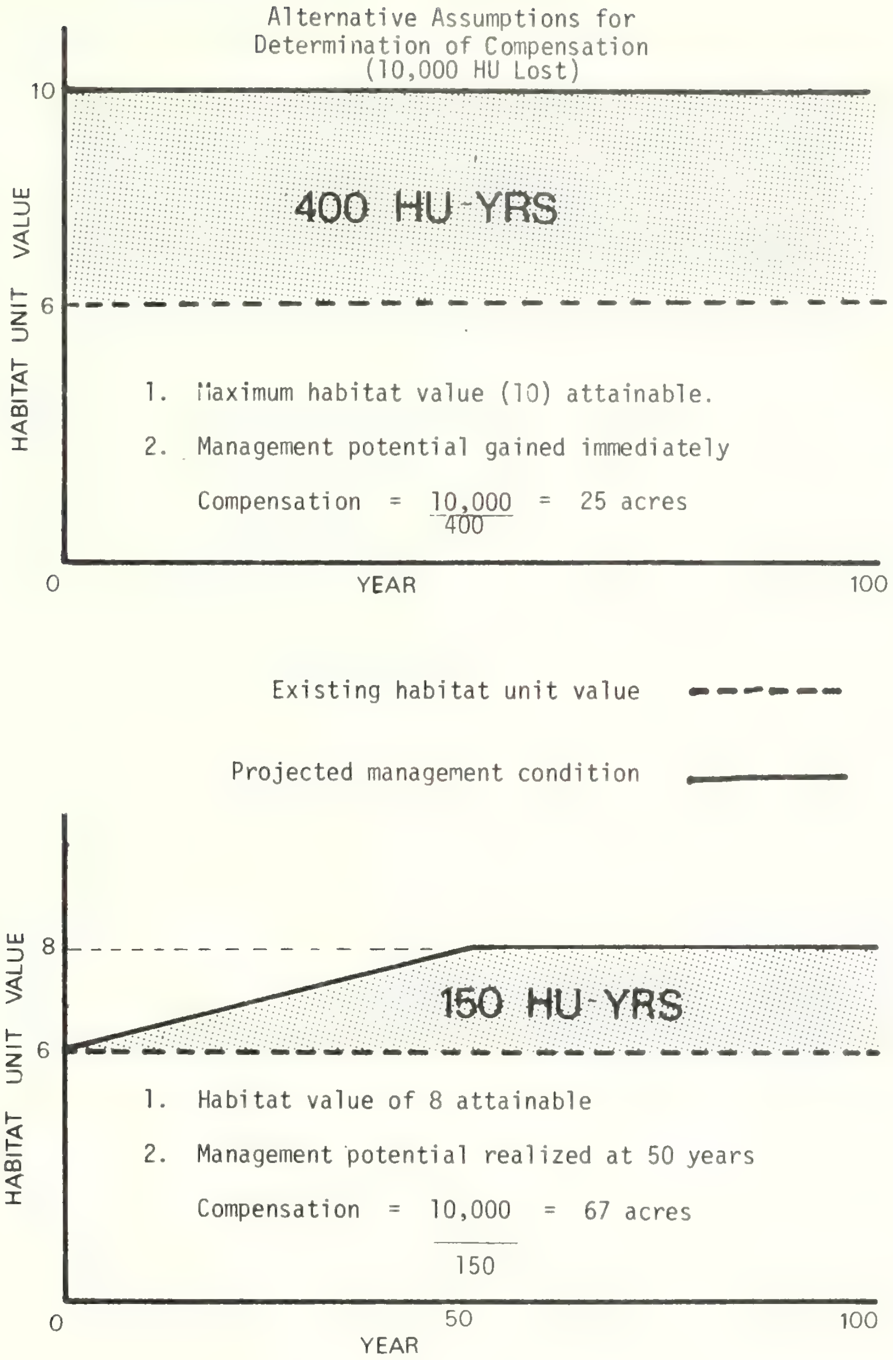


Figure 5. Alternative assumptions lead to different requirements for compensation of project losses. Upper graph, assumptions and calculations are based on "ideal" conditions. The lower is based on more realistic assumptions.

IDENTIFICATION OF CRITICAL WILDLIFE HABITAT USING AN "IMPACT RISK" MAPPING TECHNIQUE

Larry S. Thompson
Energy Planning Division
Montana Department of Natural Resources and Conservation
32 South Ewing
Helena, Montana 59601

Abstract: A method is presented for mapping areas where relative risk for adverse impact to the wildlife resource is greatest; for purposes of project planning such areas are assumed to represent "critical" wildlife impact. Impact risk was modeled using the following steps: (1) wildlife species of greatest concern are identified and ranked numerically, based upon several measures of relative importance and the relative magnitude of probable impacts; (2) a habitat map is prepared and the habitat categories rated according to potential suitability for each species; (3) the distributions and seasonal use areas of each species are mapped; (4) the distribution maps and the habitat map are digitized and combined; and (5) each resultant category is weighted according to the numerical ranking of its resident species as well as its suitability as habitat for those species. The composite map thus produced depicts five impact risk categories; for purposes of project planning the highest ranking is considered critical wildlife habitat. Examples of maps produced by this process, using different rating schemes or different means of combining resource data, are compared and applications and shortcomings of this approach to project planning are discussed.

The phrase "critical wildlife habitat" has been appearing with increasing frequency in the environmental literature, yet its meanings may be as diverse as wildlife itself, and can range from elk (*Cervus canadensis*) wintering areas to grizzly bear (*Ursus arctos*) habitat to wildlands in general. From a planning standpoint, habitat which is critical to a particular species or group of species is of concern only to the extent that it might be adversely affected by potential land use changes. Wetlands may indeed be critical to waterfowl, for example, but are not of great concern to persons involved in selecting a route for a mountain road.

In this paper, critical wildlife habitat is given a definition which I believe to be most useful in project planning: namely, "areas where the risk of adverse impact to the wildlife resource is relatively greatest." The impact risk of a particular area is closely related to several parameters which can, more or less, be quantified. These are: the relative "importance" of the wildlife resource which could be affected, the suitability of the area as habitat, the actual distribution and habitat use patterns of the animals, and the type and magnitude of probable impacts which a proposed land use change would cause in that area. Some of the parameters which determine the relative impact risk of a given area are listed in Table 1, and will be discussed in more detail later.

I will also describe a method for identifying and mapping critical wildlife habitat by modeling impact risk, using a computer process to facilitate the tradeoffs among the many species which occupy an area. It was necessary to

Table 1. Some Parameters which Influence Wildlife Impact Risk

Parameters
A. RELATIVE "IMPORTANCE" OF INDIVIDUAL SPECIES
1. Special status*
2. Worldwide abundance*
3. Restriction of distribution*
4. Reproductive potential*
5. Relative resource value*
6. Relative recreational value*
7. Relative scientific value*
8. Site specificity*
9. Habitat specificity*
10. Relative aesthetic value
11. Relative ecological value
12. Public concern
B. TYPE AND MAGNITUDE OF POTENTIAL IMPACTS
1. Displacement (short-term, long-term)*
2. Changes in natality and mortality rates (short-term, long-term)*
3. Habitat alteration (short-term, long-term)*
4. Stress (short-term, long-term)*
C. HABITAT SUITABILITY
1. Vegetation type*
2. Land use*
3. Vegetation patchiness
4. Vegetative physiognomy
5. Foliage height diversity
6. Canopy cover
7. Seral stage
8. Physiography, slope, aspect
9. Substrate (geology, soils)
10. Micro- and macroclimate
11. Elevation
12. Insolation
13. Interactions with other species (competition, predation, aggression, etc.)
14. Availability of food, water and cover
D. ACTUAL HABITAT USE
1. Habitat suitability*
2. Seasons*
3. Weather
4. Characteristics of adjacent habitats
5. Availability of other habitats
6. Extent of habitat
7. Tradition, learning (e.g., migration patterns), habituation
8. Individual preferences of animals
9. Population density, territoriality
10. Colonizing ability of animals
11. Barriers or impediments to colonization (fences, roads, water, etc.)
12. Extent and type of human disturbance
13. Competition, competitive exclusion
E. EXISTING DISTRIBUTION PATTERNS
1. Yearlong distribution*
2. Seasonal distribution*
3. High-density areas
4. Migration routes
5. Reproductive sites
6. Feeding sites
7. Bedding or denning sites

* used in this model

produce a single map showing the relative risk of adverse impact to the wildlife resource over an area of several thousand square miles during the course of utility siting studies carried out by the Energy Planning Division of the Montana Department of Natural Resources and Conservation. The following discussion describes the technique our Division developed to solve this problem in the most ecologically realistic manner possible within the constraints of time and money. I am reporting it here in the hope that it may prove useful to planners facing a similar problem.

Briefly, this method involves the following steps: (1) species of greatest concern are identified and ranked numerically, based upon several measures of relative importance and the relative magnitude of impacts; (2) a habitat map is prepared, and the habitat categories rated according to potential suitability for each species; (3) the distributions and seasonal use areas of each species are mapped; (4) the distribution maps and the habitat map are digitized by means of a raster scanner and combined; and (5) each resultant category is weighted according to the numerical ranking of its resident species as well as its suitability as habitat for those species. The composite map which results from this process depicts five "impact risk" categories, ranging from one (smallest relative impact risk) to five (greatest relative impact risk). The highest-ranking of these may be considered "critical" wildlife habitat.

This method was applied to a 2,500 square mile (4,022 km^2) study area in western Montana that includes a wide variety of habitats, from valley floors to timberline forests, and contains most species of animals found in the northern Rocky Mountains. For convenience of comparison, maps of a 500 square mile (804 Km^2) portion of this larger study area are shown at the tops of alternate pages in the remainder of this paper.

IDENTIFICATION AND NUMERICAL RANKING OF SPECIES OF CONCERN

A specific area may harbor hundreds of species and subspecies of wildlife. If we define wildlife to include all nondomestic terrestrial animals, the list includes all taxa from land snails to grizzly bears. Obviously, not all species are of equal concern; some have a relatively great importance or a high vulnerability, while others do not. The starting point in this model is the determination, on a relative basis, of which of the multitude of species found in an area are of greatest concern with respect to a particular land use decision.

A matrix (Figure 1) was devised to accomplish this relative ranking of species. Several numerical values are assigned to each species based upon a number of rating criteria; these values are then combined to produce the final ratings for each species. Two groups of criteria were used to arrive at the final ratings: (1) importance criteria (symbolized in Figure 1 by V_k, $k = 1$ to ℓ) which rank species relative to one another based on relative value, and (2) Impact Magnitude criteria (symbolized by I_m, $m = 1$ to 8) which rank species according to the probable magnitude of specific types of impacts which may affect the species in a given area or at a given season.

Species (S_i)	Area Mapped	Importance, V_k						Impact Magnitude, I_m										Final Ratings	
								Short-term				Long-term							
		V_1 (Criterion 1)	V_2	V_3	...	V_ℓ	T (Total)	I_1 (Displacement)	I_2 (Mortality)	I_3 (Habitat Alteration)	I_4 (Stress)	I_5 (Displacement)	I_6 (Mortality)	I_7 (Habitat Alteration)	I_8 (Stress)	A (Total for Occupied Habitat)	P (Total for Unoccupied Habitat)	R (Rating for Occupied Habitat)	Q (Rating for Unoccupied Habitat)
S_1	Summer-Fall Range																		
	Winter-Spring Range																		
	Yearlong Range																		
S_2	Yearlong Range																		
S_3	Yearlong Range																		
... S_j																			

Figure 1. Sample matrix for rating of wildlife species.

RELATIVE IMPORTANCE RATING CRITERIA

Several different numerical rating schemes have been devised to quantitatively estimate the importance of the various wildlife species (Flath 1975, Lonner and House 1977, Thomas 1978). For purposes of example, I will use the criteria described by Thompson (1976) and summarized in Table 2. Each species is assigned a certain number of points for each of these criteria, and these points are summed to obtain the total relative importance ratings. That is, for each of j species S_i (i = 1 to j), the total relative importance rating T_i equals the sum of points received in each of criteria V_{ik}, or

$$T_i = \sum_{K=1}^{\ell} V_{ik}$$

The exact criteria which are used for a particular project, and especially the values assigned in the matrix, will vary from region to region as well as over time, reflecting the overall importance of the wildlife resource in a given cultural context. The values which appear in the matrix are necessarily subjective, and should be the product of interaction of land managers and the public, rather than of any single individual.

It should be emphasized that our concern here is the relative ranking of species. Those species which receive a total importance rating of zero may be quite important in many respects, but are of low relative importance when compared to all other. I hope that this method, despite its limitations, will allow a finer differentiation of importance than the "big game-nongame" or "endangered-nonendangered" dichotomies so often seen.

RELATIVE IMPACT MAGNITUDE RATING CRITERIA

An adverse or negative impact to a particular wildlife species may be defined as any environmental change which: (1) reduces population size below the existing carrying capacity of the environment, (2) increases population size above carrying capacity, or (3) reduces existing carrying capacity. It is convenient to group potential wildlife impacts into one of the four broad categories described by Thompson (1976): habitat alteration, displacement, changes in mortality or natality rates, and stress. Of course, biological systems are by no means as simple as this; a complex and intricate interrelationship exists among these four somewhat arbitrary impact categories and their ultimate effect upon carrying capacity.

Table 3 shows the criteria used in our example for estimating the relative magnitude of each type of potential adverse impact for each species. This must be a relatively subjective process, because very little data are available upon which to base such predictions, and the exact response of an animal to environmental change is often impossible to predict. Still, a decision has to be made, and managers cannot always wait until they have all the answers. Thus, it may be necessary to make an "informed guess" as to the types and magnitude of the probable impacts which may result from a given project.

Table 2. An Example of a Rating Scheme Which May Be Used to Quantify the Relative Importance of Individual Wildlife Species

Criteria	Rating
(1) Special Status (U.S. Fish and Wildlife Service 1973)	
Endangered	10
Threatened	6
Status undetermined	3
"Blue List" (Arbib 1976)	1
(2) Worldwide Abundance	
Less than 100 individuals	16
101-1,000 individuals	8
1,001-10,000 individuals	4
10,001-100,000 individuals	2
(3) Restriction of Distribution	
Project area contains 1-10 percent of worldwide population	3
Project area contains 10-100 percent of worldwide population	10
(4) Reproductive Potential	
Low (one to ten offspring potentially produced in 5 years, beginning with one newborn pair)	1
Very low (<1 offspring potentially produced in 5 years, beginning with one newborn pair)	3
(5) Relative Resource Value	
Game Animals. The relative resource value of a given game species = $(B/B_{max}) \times 5$ (rounded to the nearest non-zero integer), where B = estimated biomass of local harvest of that species during the most recent hunting season, and B_{max} = the greatest value of B received by any of the game species found in the area.	
Furbearers. The relative resource value of a given fur-bearing species = $(H/H_{max}) \times 2$ (rounded to the nearest non-zero integer), where H = estimated dollar value of local harvest of that species during the most recent season, and H_{max} = the greatest value of H received by any one of the furbearers found in the area.	
All Other Species. The relative resource value of all other species = 0.	

TABLE 2 (Concluded)

(6) Relative Recreational Value

Game Animals. The relative recreational value of a given game species = $(D/D_{max}) \times 5$ (rounded to the nearest non-zero integer), where D = estimated hunter days spent locally in pursuit of that species during the most recent hunting season, and D_{max} = the greatest value of D received by any of the game species found in the area.

All Other Species. The relative recreational value of all other species = 0.

(7) Relative Scientific Value

Species or subspecies endemic to the area	5
Relict population essentially restricted to the area	2
Other populations of unusual scientific interest	1

(8) Site Specificity

Species confined to specific, isolated sites or colonies	2
All other species	0

(9) Stenotopy (Habitat Specificity)

Species requiring climax or near-climax plant communities	2
Species having other very narrow habitat requirements	1
All other species	0

Table 3. An Example of a Rating Scheme Which May Be Used to Quantify the Relative Magnitude of Impact to Individual Wildlife Species Resulting From a Certain Land Use Change.

Nature of Impact	Value Rating
No significant effect on population levels	0
Possibility of significant:	
Short-term displacement	1
Short-term increase in mortality rates	2
Short-term decrease in carrying capacity	3
Long-term increase in mortality rates	7
Long-term decrease in carrying capacity	10
Possible elimination of populations from study area	25

Notice that, in Table 3, short-term and long-term impacts are considered separately. Species which differ seasonally in distribution and/or impact susceptibility may receive more than one impact rating in each category; seasonal use areas are merely treated as separate species. For example, the susceptibility of elk to impacts affecting food availability may be greater on the winter-spring range than on the summer-fall range, so these two seasonal use areas may be rated separately under the category "habitat alteration." Species which receive separate ratings by season also receive a year long relative impact magnitude rating, which is simply the worst of the seasonal ratings listed for each type of impact. Species for which the magnitude of probable impacts differs greatly from one area or habitat to another may be treated in a similar manner.

Each species S_i (or a subset of its range) is given two total relative impact magnitude values. The first of these, symbolized by A_i, represents probable impacts within the occupied range of the species, and equals the sum of the individual impact ratings I_{im}:

$$A_i = \sum_{m=1}^{8} I_{im}$$

The second rating (P_i) represents probable impacts within potential (unoccupied) habitat, or areas outside the defined range of the species. Since animals are not present in these areas today, short term impacts due to displacement, mortality, and short-term alteration of habitat will not occur. However, long-term impacts will affect the future suitability of these areas as habitat. One possible estimate of P_i is simply the sum of long-term impacts only, or for each S_i:

$$P_i = \sum_{m=5}^{8} I_{im}$$

It may be advisable to use a different function which gives a lower value to P_i, since unoccupied habitat may be vacant for reasons not otherwise considered in this model (proximity to urban areas, ecological differences which are not presently known, etc.) This will be discussed later.

Note that species which are in no danger of sustaining significant impacts, no matter how important, receive a total relative impact magnitude value of zero and drop out of the matrix at this point.

FINAL RATINGS

The final ratings, symbolized R_i for occupied habitat and Q_i for potential habitat, are obtained by multiplying the importance rating total T_i for each of j species S_i by the appropriate total relative impact magnitude value A_i or P_i:

$$R_i = (T_i)\ (A_i)$$

$$Q_i = (T_i)\ (P_i)$$

Species of concern may be defined as those receiving final ratings greater than some arbitrary cutoff value. In the study area, no endangered, threatened, relict, or endemic species were found to be resident, and the elk, an important game animal, received the highest numerical rating. The 14 highest-ranking species were arbitrarily chosen as species of concern for use in this example.

CLASSIFICATION AND MAPPING OF WILDLIFE HABITAT

The objective of habitat classification is to designate relatively homogeneous units that recur across the landscape and which are of differential suitability in fulfilling the requirements of various wildlife species. However, the number of interrelated environmental variables which determine habitat suitability for each particular species is formidable. A few of the most important are listed in Table 1 under Potential Habitat Suitability (see also Balda 1975, Thomas 1978).

No habitat classification scheme can differentiate among all habitat variables discerned by the animals themselves, or separate all microhabitats which are essential to the various species. Thus, any categorization of habitat must necessarily be a gross generalization, because it keys in on only a few of the many variables which biologists believe to determine suitability. Pragmatically, habitat categories should be specific enough to adequately represent major differences in habitat which determine overall use by species of concern, yet sufficiently general that they may realistically be mapped and worked with. The number of categories chosen and the scale and accuracy of habitat mapping are, of course, important determinants of the accuracy with which critical habitat may be mapped.

Only the first two of the variables listed (Table 1) under Potential Habitat Suitability were used in this model; it was assumed that land use practices and native vegetation reflect differences in such variables as climate, substrate, slope, and aspect, and in turn determine canopy cover, associated animal communities, food availability, etc. The "habitat type" classification scheme of Pfister et al. (1974), which is based upon biotic potential of land units and the plant associations they would support at climax, was used in mapping forest communities.

Some 52 land use and habitat type categories were originally mapped at a scale of 1:65,000 using aerial photographs. These were later combined (Table 4) into 15 much broader categories which were mapped at a scale of 1:250,000 (Figure 2).

Although vegetation type and land use were the only two variables used in this example, it is possible to model habitat suitability by overlaying maps of any additional environmental variables which can be mapped (such as soil types or precipitation isopleths).

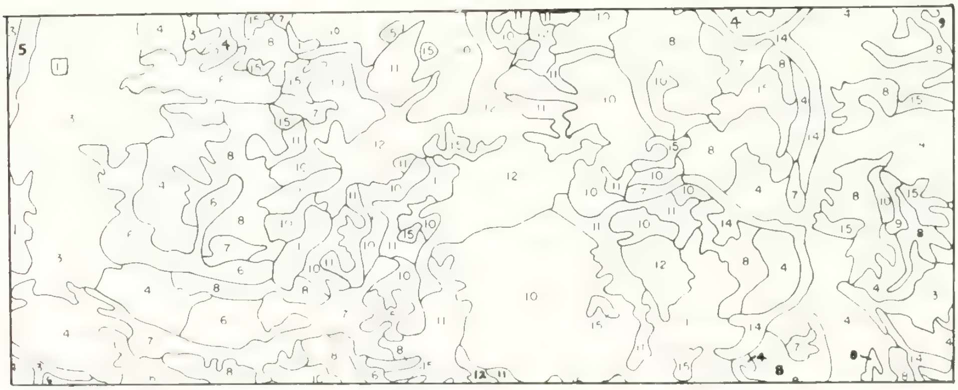


Figure 2. Map of wildlife habitat categories used in the example described in the text.

Table 4. Wildlife Habitat Categories Which Were Mapped and Rated in This Study

No.	Category	Component land use categories or habitat types
1	Man-altered land	Urban, small communities, scattered built-up areas, industrial
2.	Large water areas	Large water areas
3.	Agricultural	Irrigated cropland, dry cropland, bottomland mix
4.	Bunchgrass	Grassland
5.	Cottonwood	Cottonwood
6.	Timber/Bunchgrass	PF/Agsp, PP/Agsp, DF/Agsp, PF/Juco, DF/Aruv
7.	Ponderosa Pine (PP)-Douglas Fir (DF/Shrub)	PP/Syal, DF/Vaca, DF/Phma, DF/Vagl, DF/Syal, DF/Spbe
8	DF/Grass and forb	DF/Xete, DF/Libo, DF/Caru, DF/Cage
9	Lodgepole pine	Lodgepole pine series
10.	Subalpine fir (AF)-grand fir (GF) dry	DF/Xete, AF/Vaca, AF/Xete, AF/Vagl, AF/Vasc, AF/Vasc, AF/Caru
11.	AF-GF moist	GF/Clun, AF/Clun, S/Gatr, AF/Gatr, Pi/Gatr, AF/Caca, AF/Libo, AF/Mefe, AF/Alsi, Pi/Libo
12.	Subalpine and timberline	AF(WBP)/Vasc, AF/Luhi, WBP-AF, AL-AF, WBP
13.	Scree and rock	Rock, forested rockland, scree
14.	Willow and Alder Flats	Meadow, alder glades, willow
15.	Logged	Logged

RATING OF HABITAT CATEGORIES

Each of the parameters that determine habitat suitability may be thought of as an axis of the "n-dimensional hypervolume" which describes the niche (sensu Hutchinson 1957, Maguire 1973) of a particular species. To survive, a species must exist within the limits of tolerance for each environmental variable. Within this permissible range of variation, a continuous gradation exists between "marginal" suitability at the extremes and "optimal" suitability somewhere in between. Thus, habitats may be rated as optimal or suboptimal for each of the variables determining suitability. In real life, this is difficult or impossible to accomplish, and it is often necessary to infer overall suitability from such empirical evidence as relative use or population density.

The rating system used for habitat suitability in this model (Table 5) is based partly on relative use and partly on the extent to which a particular habitat fulfills the requirements of a species at a given season. Each of v habitat categories is assigned a rating H_{iu} (u = 1 to v) as to potential suitability for each of j species of concern S_i. The cottonwood (Populus deltoides) type, for example, is not used at all by mountain goat (Oreamnos americanus) populations, and hence receives a rating of zero for the mountain goat, the lowest possible. Willow and alder flats, on the other hand, fulfill an essential requirement of moose (Alces alces) populations which is met by no other type. Hence, this type is assumed to be limiting and receives a value of four--the highest possible--for the moose. As was the case with the impact magnitude ratings discussed earlier, species which receive separate ratings for different seasons also receive an annual rating, which is merely the highest of the seasonal ratings listed for each habitat category. These ratings are based primarily on published data concerning habitat use.

This method of rating habitat suitability assumes that the habitat categories mapped are homogeneous and identical wherever they occur, and that juxtapositions of different types do not influence use, although in many cases microsites, seres, or ecotones within a given habitat category may be highly preferred, while adjacent sites within the same category may be used only marginally. This model also assumes that use is proportional to habitat suitability, which is not always true (see following section).

An additional problem results from the definition of critical habitats (those which are limiting or which contain limiting elements) because the extent to which a type may be considered "limiting" is a function of the particular classification used. For example, consider a hypothetical forest bird which is restricted to coniferous forests. The forest type can considered limiting or essential to this bird, because if the forest is done away with the bird will also disappear. However, if the same area is mapped using a finer breakdown of habitat categories, including several coniferous forest types which are used by the bird, no particular type in itself is limiting, since if one forest type is destroyed populations can persist in several other types. If habitat categories are subdivided further, so that rock cliffs (essential nesting sites for the bird) are mapped, areas appear once again.

Table 5. An Example of a Rating Scheme Which May Be Used to Quantify Habitat Suitability

Rating	Suitability	Definition	Characteristics			Examples		
			Preferred?	Necessary?	Fulfills all requirements?	Species	Season	Category
0	No use	Receives very little or no use under normal circumstances	No	No	No	Mountain goat	Winter	Cottonwood
1	Marginal	Used only when other types not available or during movement between preferred types; relative use generally less than relative extent of type	No	No	Possibly	Lynx	Summer	Agricultural
2	Adequate	Used when encountered but not actively sought or preferred over other types. Relative use roughly proportional to relative extent of type	No	No	Possibly	Elk	Summer	Lodgepole Pine
3	Preferred	Preferred over other types when available; relative use greater than relative extent of type	Yes	No	Possibly	White-tailed deer	Spring	Cottonwood
4	Limiting or essential	Adequately fulfills an essential requirement of the species which is met by no other type; removal of this type may drastically reduce or eliminate populations. Relative use may or may not be greater than relative extent of type. Includes types used exclusively	Possibly	Yes	Possibly	Moose	Winter	Willow Bottoms

MAPPING OF DISTRIBUTION PATTERNS

There are many determinants of habitat use other than habitat suitability (some have been listed in Table 1 under Actual Habitat Use), and populations of a given species do not always occur in all apparently suitable areas within their geographic range. Hence, it is often desirable to delineate local distribution of various species within the study area, and to identify seasonal use areas, high-density areas, and other distinct segments of the year long range (see Table 1 under Existing Distribution Patterns). Mapped distributional boundaries are best thought of as lines of probability, rather than absolute distributional limits, because individuals may occasionally wander far from their usual range. As an example of the distribution maps used in this study, the general seasonal distribution of elk in the study area is shown in Figure 3. This map was prepared using the literature and information furnished by the Montana Department of Fish and Game. In the case of species such as the marten (Martes americana), which occur more or less uniformly throughout suitable habitat, distributional boundaries need not be mapped if the appropriate habitat units have been delineated.

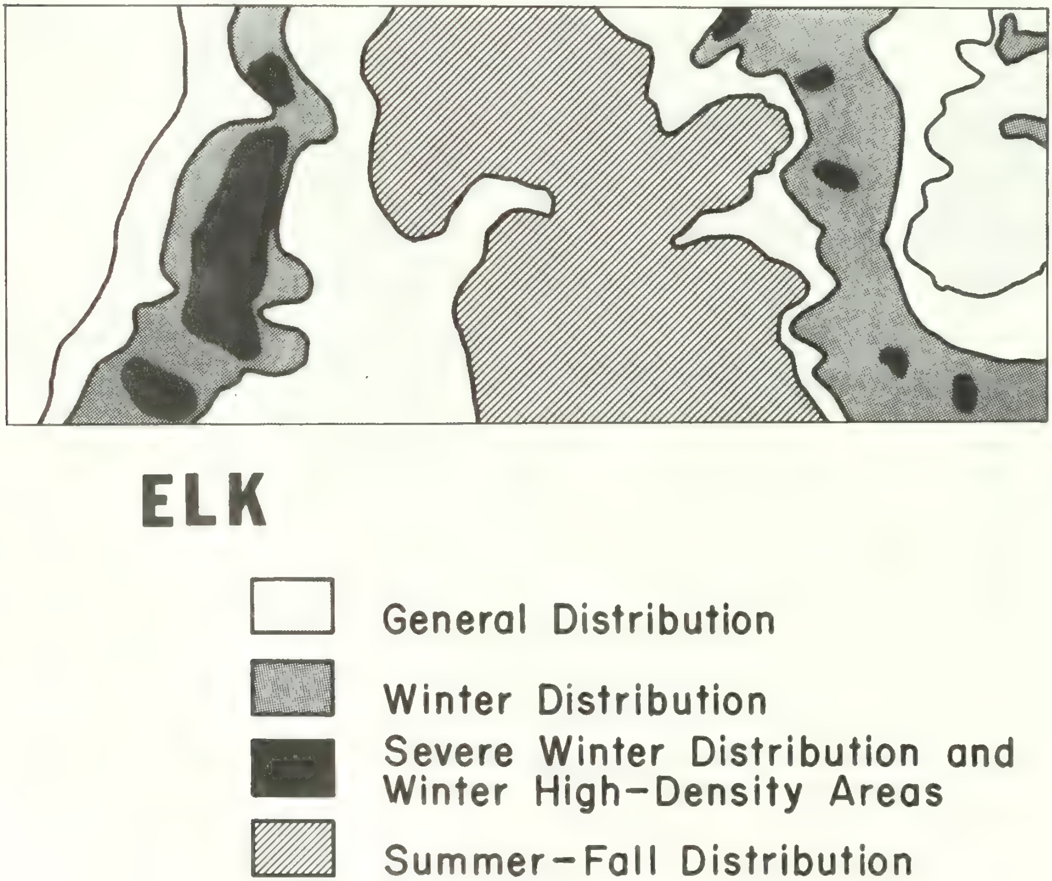


Figure 3. Seasonal distribution of elk.

MODELING WILDLIFE IMPACT RISK

Two separate ratings have been obtained thus far for each wildlife species and/or subset of its range: (1) the final ratings R_i and Q_i, which provide an estimate of the relative magnitude of potential impacts, and (2) potential habitat suitability ratings H_{iu}. Possible methods of combining these ratings with the distribution and habitat maps, to produce a map showing wildlife impact risk, will now be described.

The simplest model for mapping wildlife impact risk involves merely combining each final rating R_i with the habitat rating H_{iu} for each of j species and v habitat units. If these values are multiplied, a given habitat unit u will receive the following final weighting W_u:

$$W_u = \sum_{i=1}^{J} (H_{iu}) (R_i)$$

The products for each of j species are thus summed to obtain a value for each mapped unit; these may then be scaled as necessary, the highest-ranking categories representing "critical wildlife habitat." This scaling of sums was done by computer after the habitat map was digitized, and the resulting computer-generated map is shown here as (Figure 4). In this and subsequent maps, final weightings (W) were scaled from 1 to 5 based on the maximum value W_{max} received by a mapped unit (Table 6).

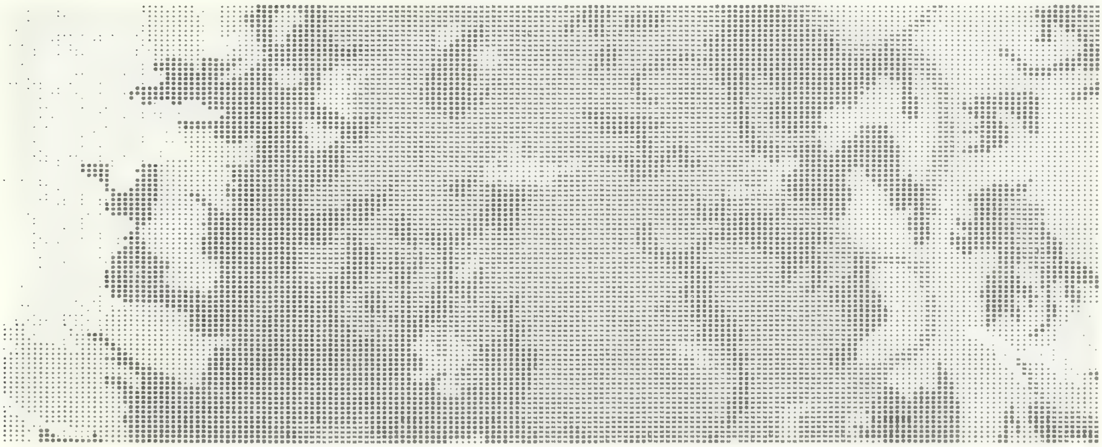


Figure 4. Computer-generated composite impact risk map based upon habitat suitability only.

Table 6. Scaled Values of Final Weightings and Their Definition

Range of final weightings (W)			Scaled value	Relative impact risk	map symbol
0	-	Wmax/5	1	Smallest	
(Wmax/5)+1	-	2Wmax/5	2		-
(2Wmax/5)+1	-	3Wmax/5	3		+
(3Wmax/5)+1	-	4Wmax/5	4		
(4Wmax/5)+1	-	Wmax	5	Greatest	

Thus, the darkest areas in Figure 4 represent areas of greatest relative impact risk, or "critical habitat." This approach, however, does not take into account known distribution patterns or seasonal differences in habitat value. Also, there is no provision for differentially treating potential and occupied habitat.

A second possible model for mapping wildlife impact risk assumes that, areas within the defined year long or seasonal range of a species roughly define "critical habitat" because they are clearly of greater importance than areas outside the range. Thus, if a given point on the map is within the range of species S_i, it receives a weighting of R_i; if outside the defined range, it receives a weighting of zero. The final weighting that point receives is equal to the sum of the final ratings R_i for all species whose ranges include that point, or

$$W = \sum_{i=1}^{j} R_i$$

In other words, the distribution maps are simply digitized and combined. These weightings are also scaled from 1 to 5, the highest ranking areas again defining "critical wildlife habitat." In the map that results (Figure 5) note the differences from Figure 4. Potential habitat (areas outside the range of a given species) may be assigned values, other than zero, which are a function of the final rating of that species. This approach, however, fails to account for differential habitat suitability within the defined range of a species.

A third and more realistic model--the one we have found to be most useful--is actually a combination of the two described above, and involves combination of the habitat map with the distribution maps, and appropriate rating of each resultant category. This combination permits consideration of differences in habitat suitability, as well as differential treatment of potential and occupied habitat. Each point on the map is assigned j numbers, one for each of the j species of concern, as follows:

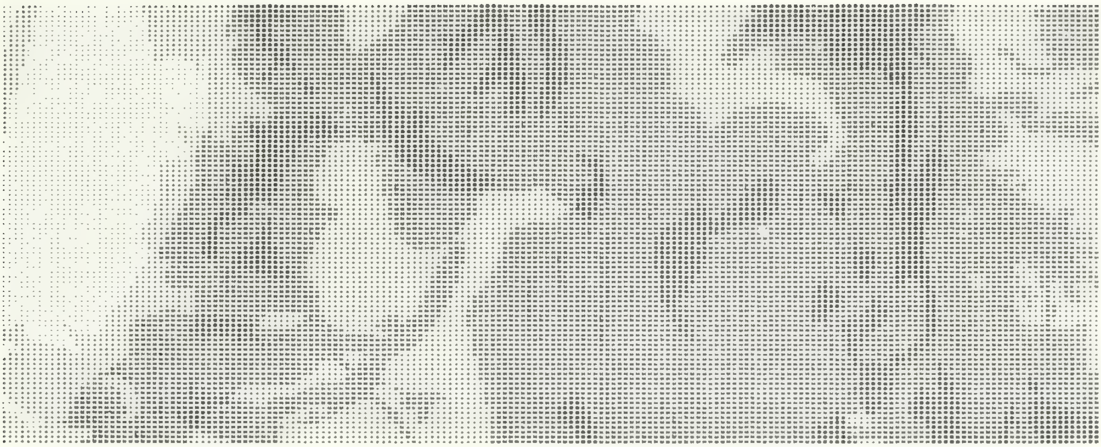


Figure 5. Composite map based upon existing distribution patterns only.

1. The distribution map for a given species S_i is overlain with the habitat map.

2. If a point falls within a given segment of the annual range of species S_i, it receives a value equal to the product of the final rating R_i that species receives for that segment, and the habitat rating H_{iu} the species receives for the habitat unit u in which the point is found. Thus, seasonal differences in distribution, in R and in H_u, are taken into account.

3. If a point falls within the potential range of species S_i it may receive a value equal to the product $(Q_i)(H_{iu})$ or some function of the product noted in (2) above. As mentioned earlier, potential habitat should probably be rated much lower than occupied habitat; in the example used here, it receives a value equal to (R_i) (H_{iu}).

4. It may be desirable to treat certain areas of unoccupied habitat as being outside the potential range of species S_i; points falling in these areas receive a value of zero. For example, in the case of the bighorn sheep (*Ovis canadensis*) occupied range was treated as such, former winter and summer ranges were treated as potential habitat, and all other areas were given a value of zero.

These steps are repeated for each of the j species of concern, resulting in a series of numbers being assigned to each point on the map. These numbers are then summed for each point to obtain the weighting W which the point receives:

$$W = \sum_{i=1}^{j} (R_i, Q_i) (H_{iu})$$

These values are then scaled to produce the final "wildlife impact risk" map. This method applied to the study area results in Figure 6, where the highest ranking categories may be considered "critical wildlife habitat." The areas defined here as critical habitat include both winter ranges and summer security areas used by a number of species.

The computer system used in generating the maps shown here has a minimum resolution of 10 ha (0.04 mi^2), that is, each individual "point" (represented by one symbol on the computer-generated maps) represents an area of 10 ha. Critical sites which are this size or smaller (such as individual bird nest sites, leks, dens, rookeries, ponds, colonies, etc.) may be plotted directly on the computer-generated map.

LIMITATIONS AND APPLICATIONS

The quality of wildlife impact risk maps produced by this technique can, of course, be no better than the quality of the data which goes into the model, and in several areas (particularly impact prediction and rating of habitat suitability) the amount of presently available data is sketchy. The state-of-the art is such that much of the information necessary to make intelligent trade offs is lacking or inadequate, and in rating wildlife values we may be trying to quantify the unquantifiable--which, in the words of economist E. F. Schumacher, constitutes but "an elaborate method of moving from preconceived notions to foregone conclusions." Thus, this method may be premature in terms of availability of data. Also, such a method as this requires many simplifying assumptions, some of which may not be ecologically realistic. Some degree of subjectivity is inherent in the system, and the possibility for bias exists throughout.

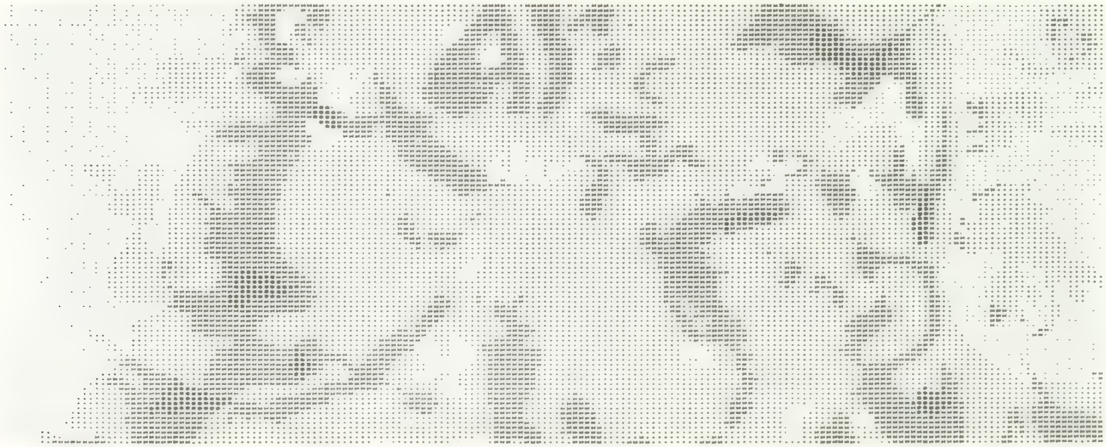


Figure 6. Composite map based upon both habitat suitability and existing distribution patterns (preferred method).

One danger in using the term "critical" to describe wildlife habitat is the implication that other habitat is not critical. This sometimes leads to the fallacy that, if critical habitat is preserved, surrounding habitat may be done away with or altered at will. It has been suggested by mining companies, for example, that no strip mining be carried out within prairie dog (Cynomys ludovicianus) towns containing the endangered black-footed ferret (Mustela nigripes), but that surrounding areas be strip mined up to the edge of such towns leaving them as islands within the mining spoils. It may be argued that all habitat occupied by a species is critical, because it contributes in some way to maintenance of populations of that species; indeed, critical habitat is defined in the Federal Register (22 April 1975) as "...the entire habitat or any portion thereof, if, and only if, any constituent element is necessary to the normal needs or survival of that species."

In spite of these limitations, this model has been applied successfully in utility siting studies, and has proven much more valuable than distribution maps alone in identifying critical areas of greatest impact risk. Its usefulness is greatest in siting studies and impact assessments concerning impacts which are relatively site-specific--such as logging, road construction, strip mining, etc.--rather than those concerning such diffuse impacts as air pollution and increases in recreational use or hunting pressure.

While intended as a means of raising "warning flags" over areas of high impact risk, and not as a management tool for enhancement of wildlife numbers, it may be applied with some modification to traditional wildlife management. It should be used only as a first step, as a tool to zero in on areas requiring a closer look--computer printouts should never be mistaken for reality, and the dangers of putting too much faith in computers cannot be overemphasized.

The method presented here also has a flexibility shared by few other systems. As mentioned earlier, almost any number of overlays in addition to the vegetative habitat map, e.g., soils, slope, elevation, precipitation, may be combined to refine the definition of habitat categories. It can be modified to model impact risk for certain types of impacts which are especially pertinent to a given situation. For example, several studies (Sullivan and Shaffer, 1975; Diamond 1976) have stressed the impacts associated with fragmentization of large unbroken tracts of habitat. These may be treated in this model by combining an overlay showing contiguous roadless blocks of land with the habitat and distribution maps, and by assigning higher impact magnitude values to points falling within such areas.

It is also possible to experiment with variations on the model described here, and to see the effect on the impact risk map. Figure 7, for example, was created by assuming the extreme case that all species would suffer the same magnitude of impact, or that relative impact magnitude is unknown. While at first glance this looks quite different from Figure 6, since much more of the area is dark, notice that areas of relatively greatest impact risk are roughly the same as in the other printouts. Thus, slight errors in the estimation of impact magnitude should not detract greatly from the usefulness of the map produced. Figure 8, which was produced using only data for ungulates, is also quite similar to Figure 6. Note in particular the areas of high impact risk at the grassland-forest ecotone in the upper left of the various maps.

A description of the computer hardware and software used to produce these maps has been given by Tsao (1975) and Clifford (1977). A computer process similar to the one described here has been developed to model sediment risk; more information on this is available from the author.

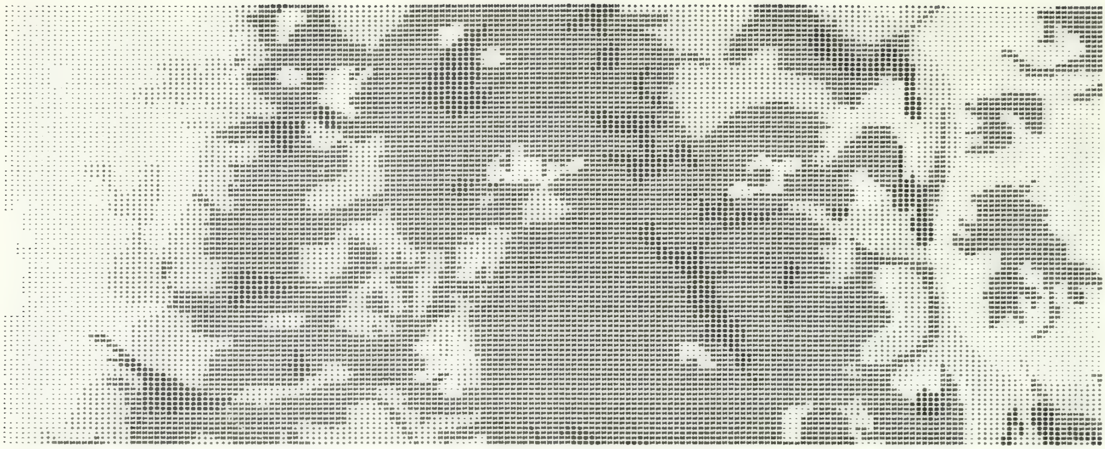


Figure 7. Composite map produced by assuming that the magnitude of probable impacts is identical for all species of concern.

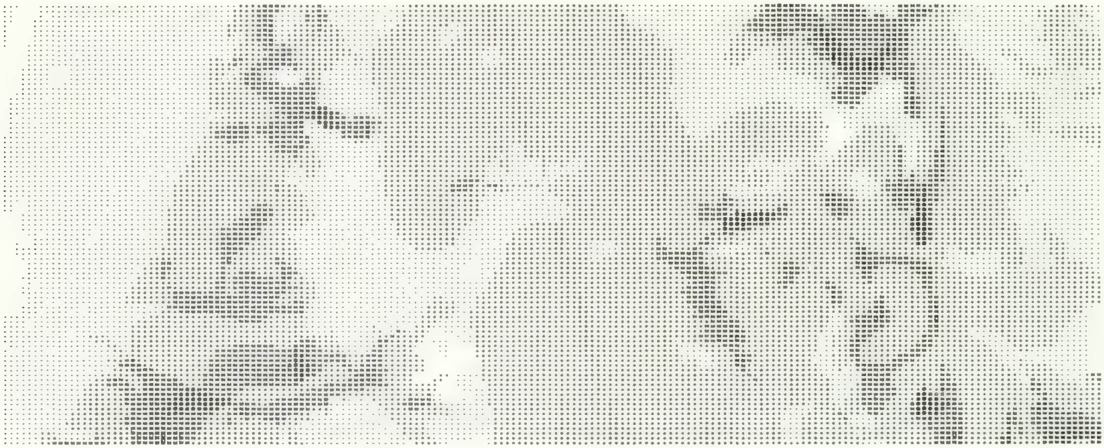


Figure 8. Composite map produced using data on ungulates only.

ACKNOWLEDGEMENTS

The methodology presented here was developed during the course of siting studies conducted by the Energy Planning Division of the Montana Department of Natural Resources and Conservation, under the direction of Albert Tsao and Lynn Brant. Dwight Clifford developed the software used in preparing the computer-generated maps, and Richard Prodgers produced the original map of forest habitat types used in preparing the wildlife habitat map. Ann Crowner, Ralph Driear, Pat Farmer, Les Marcum, and Leslie Pengelly kindly reviewed an earlier version of this manuscript. Graphics are by the Department's Cartography Bureau, and Pam Goddard assisted with typing.

LITERATURE CITED

Arbib, R. 1976. The blue list for 1976. Am. Birds 29:1067-1079.

Balda, R.P. 1976. Vegetation structure and breeding bird diversity pp. 59-80 in D.R. Smith (ed.), Proceedings of the Symposium on Management of Forest and Range Habitats for Nongame Birds. USDA For. Serv. General Tech., Rep. WO-1.

Clifford, D. 1977. User's Manual for Raster Software System. Montana Dept. Nat. Resour. and Conserv., Helena. 57 pp.

Diamond, J.M. 1976. Island biogeography and conservation: strategy and limitations. Science 193:1027-1029.

Flath, D. 1975. Montana's Nongame and Endangered Species Resource Program. Montana Dept. Fish and Game, Helena. 12 pp.

Hutchinson, G.E. 1957. Concluding remarks. Cold Spring Harbor Symp. Quant. Biol. 22:415-427.

Lonner, T. and V. House. 1977. How much is wildlife worth? Montana Outdoors, 8:46-53.

Maguire, B. 1973. Niche response structure and the analytical potentials of its relationship to the habitat. Am. Nat. 107:213-246.

Pfister, R.D., B. L. Kovalchik, S.F. Arno, and R.C. Presby. 1974. Forest Habitat Types of Montana. Intermountain For. and Range Exp. Stn. and Northern Region, U.S. For. Serv., Missoula, Montana. 213 pp.

Sullivan, A.L., and M.L. Shaffer. 1975. Biogeography of the megazoo. Science 189:13-17.

Thomas, J.W. 1978. Forest-wildlife relationships in the Blue Mountains of Washington and Oregon. USDA For. Serv. Range and Wildl. Habitat Lab., La Grande, Oregon, in press.

Thompson, L.S. 1977. Wildlife and land use change: some considerations in assessing impact risk. Western Wildlands, 3:18-24.

Tsao, A. 1975. ERGIS (Environmental Resources Geo-Information System) Data Bank for Land and Resource Utilization. Montana Dept. Nat. Resour. and Conserv., Helena. 102 pp.

USDI Bureau of Sport Fisheries and Wildlife. 1973. Threatened Wildlife of the United States. Resour. Publ. 114, U.S. Gov. Printing Office, Washington, D.C. 289 pp.

ECOSYSTEM TROPHIC RELATIONSHIPS IN HABITAT CLASSIFICATION

Norman R. French
Natural Resource Ecology Laboratory
Colorado State University
Fort Collins, Colorado 80523

Abstract: Recent advances in ecology aid in understanding the results of environmental modification and methods of habitat utilization. Structural attributes of ecosystems affect their functional characteristics and capabilities. Competition and predation represent species interactions that determine community structure. Many of these relationships are expressed in the characteristic biomass trophic pyramids of ecosystems. Knowledge of structural organization, energy flow, and organism interactions can be incorporated in classification of habitats.

INTRODUCTION

A carefully developed classification of habitat types is an important step because it is fundamental to evaluation of the susceptibility of natural environments to modification, commonly called impact assessment, and to the utilization of the full habitat potential, referred to as wildlife or natural resource management. At the present time these important fields of endeavor encompass a broad range of experimental and theoretical activities. A careful and systematic approach to habitat classification can provide a starting point and a paradigm for organization of these activities.

Ecology has made tremendous strides as a science in recent years. It has developed from the descriptive discipline of the early naturalists to a modern empirical and theoretical science that has a great deal to contribute to the welfare of modern man. It is appropriate that such a developing science should begin to synthesize its knowledge and from such synthesis to formulate principles or paradigms which purport to explain the organization or function of natural systems. One such paradigm is that ecosystems are organized along the lines of energy flow in the form of trophic pyramids. These pyramids reflect the major states of the system in which energy is captured and utilized for production before being passed on to another state variable of the system (Figure 1). A state variable of an ecosystem, in the terminology of systems analysis, is a compartment, or an easily recognized component of the ecosystem which contains a certain amount of matter and energy which we can measure. This approach to ecology emphasizes whole ecosystems or large subsections of them and attempts to understand ecosystem organization and functioning in terms of the entire complex of interacting events. Such an approach has been used to determine patterns of energy transfer and nutrient cycling in ecosystems (Likens et al. 1967, Reichle 1975).

One of the areas of ecology in which striking advances have been made in the last decade has been that of understanding patterns of species distribution on islands, and the dynamics of immigration and extinction that are responsible for the maintenance of these patterns (Figure 2). MacArthur and Wilson (1963) presented the theory of island biogeography in a paper which led to experimentation and further elaboration and

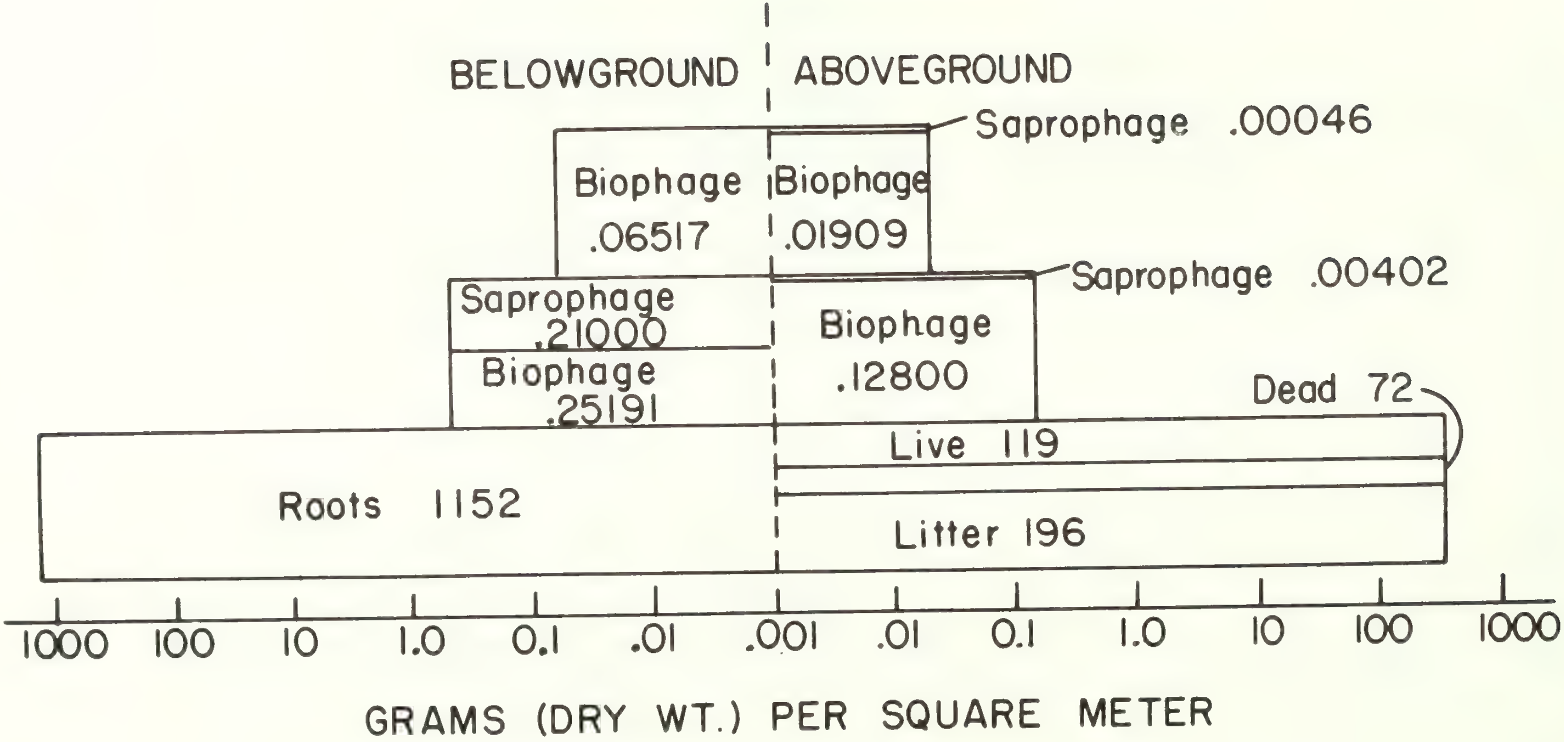


Figure 1. Trophic biomass pyramid for ungrazed shortgrass prairie. (Pawnee Site) on 23 August 1972. Below-ground biomass is shown to the left, above-ground to the right, both plotted on a logarithmic scale. Vertical divisions of each level are on a linear scale.

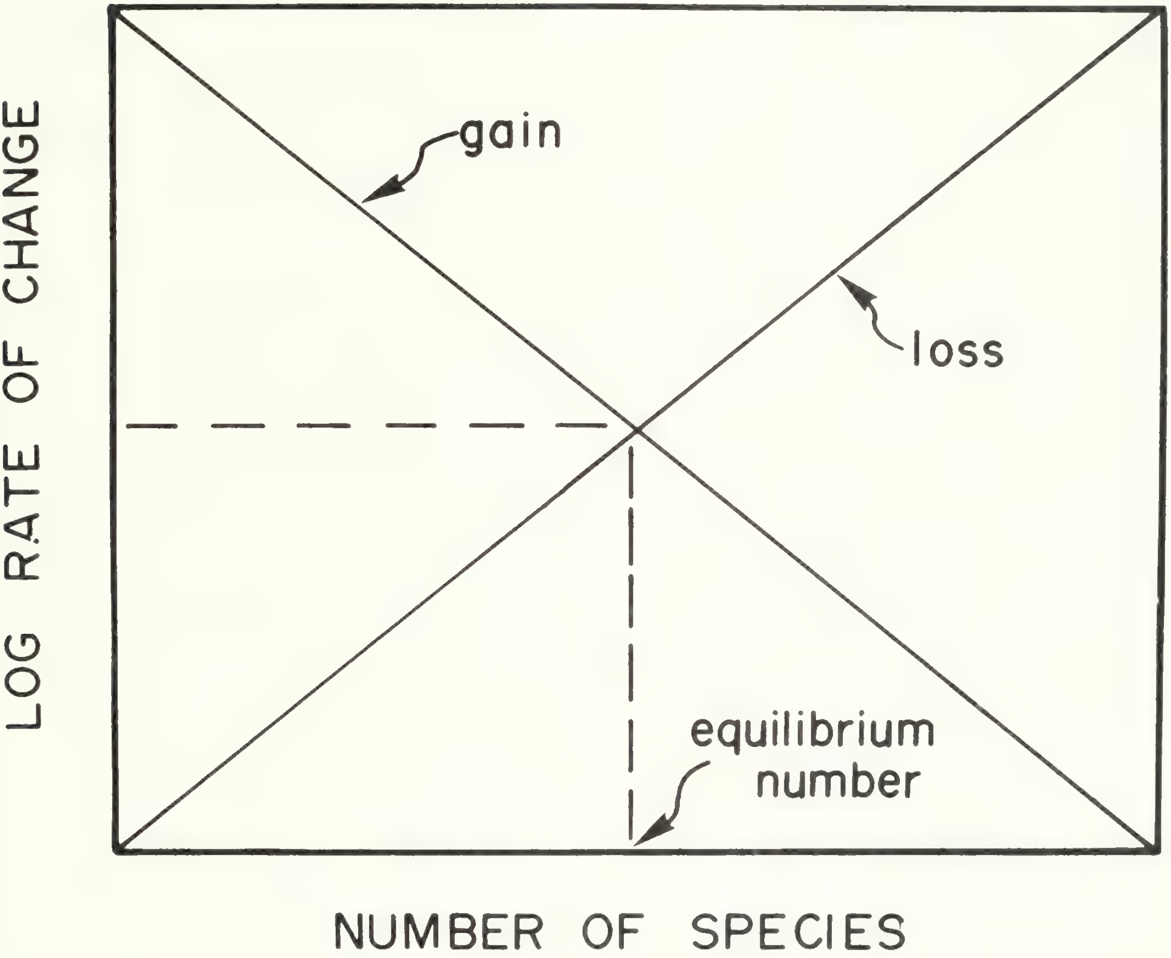


Figure 2. Determination of number of species on an island from rates of gain (immigration) and of loss (extinction) (from MacArthur and Wilson 1967). The equilibrium number of species results when rates of gain and loss of species are equal.

confirmation of the model (Simberloff 1974). Island area is the principal factor identified with increasing species diversity, but the underlying biological reasons for this area effect must certainly be related to habitat diversity, though this is more difficult to demonstrate experimentally.

Two concepts that have aided greatly in the systematic collection of ecological information for the study of species interactions are the niche and the guild concepts. Definition of a niche has suffered from some early confusion in the ecological literature. Originally defined on the basis of habitat or space that a species is utilizing, it was later redefined on the basis of a species functional role in a system (Grinnell 1917, Elton 1927). It was redefined by Hutchinson (1958) who incorporated elements of both of the previous definitions. The new definition included an infinite number of attributes of a particular species, thus encompassing all the environmental and physiological factors which determine the existence of a species. This conceptually pleasing but practically unwieldy model was applied by MacArthur (1968), who restricted measurements to one or two of the most significant components of an animal's niche, thereby obtaining a useful indication of interaction and avoiding the confusion of the technical definition.

The niche concept is particularly useful because it enables us to compare the interactions of divergent organisms, regardless of their taxonomic positions. The niche concept is useful in evaluation of habitat because habitat can be defined as the sum total of all niche dimensions utilized by the species community of a given area. Each species has a given set of requirements supplied by the habitat, but exploits only a portion of the total habitat. There is a certain amount of overlap among species in the resource dimensions that are utilized; this is referred to as niche overlap. Minimizing niche overlap determines the number of species that can occur in a particular habitat.

The guild concept (Root 1967) is a useful technique for comparison of different communities. A guild is a functional category used for combining species that overlap significantly in their utilization of a particular resource, that is, along one dimension of their respective niches (Figure 3). Species may differ slightly in their methods of exploitation of the particular habitat dimension. The presence and relative importance of different guilds provides a convenient means for lumping a complex mosaic of taxonomic entities into a reasonable number of units that may be compared to similar units in an adjacent or different community. A guild, then, may refer to ground foraging insectivorous organisms in a habitat, which might include ground foraging birds, spiders, grasshopper mice (Onychomys spp.) and certain insects. This ground feeding guild would be distinct from an aerial feeding insectivorous guild which might include dragonflies, flycatchers, and swallows.

A system of habitat classification should obey the law of parsimony; that is, the classification should be a simplification of the real system. Reduction in the number of components to a few major ones is essential. The niche concept can be useful in reducing the total habitat requirements of organisms to key factors, and the guild concept can be used to reduce the total number of species to a set of key components.

A system of classification based upon natural characteristics of ecosystems, and incorporating the basic principles of community organization, is most likely to be useful for assessment, management, and prediction. The following discussion is a brief review of some major ecosystem characteristics, with emphasis on experience gained in the International Biological Program (US/IBP), and some current concepts in evolutionary ecology that reflect

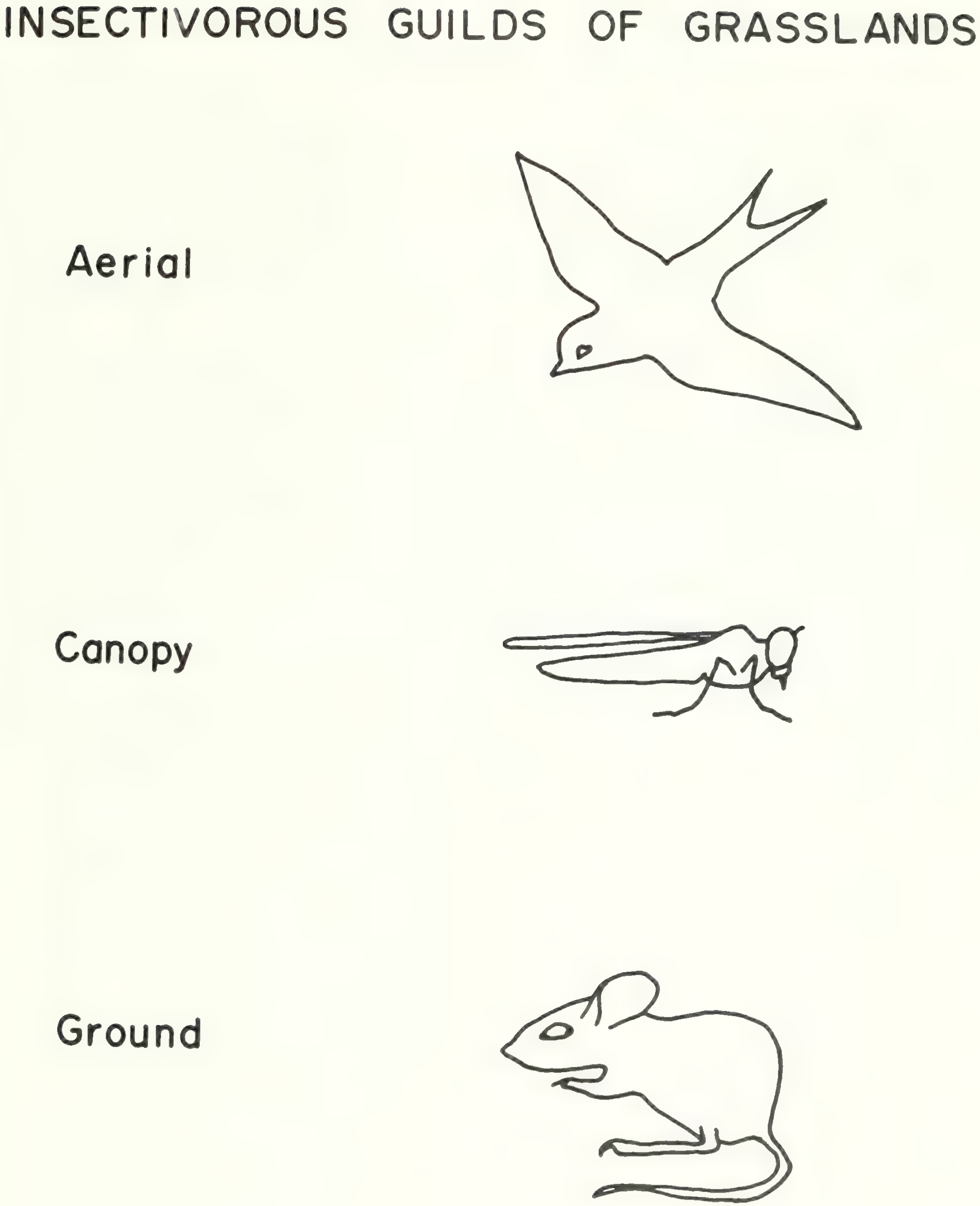


Figure 3. Insectivore guilds of the shortgrass prairie: aerial-foraging swallow; canopy-foraging robberfly; and ground-foraging rodent.

important components of community organization. Finally, I will attempt to extract and summarize the principal components of ecosystem structure which should be considered for incorporation in a habitat classification system. Emphasis here is on terrestrial communities, but principles are applicable to aquatic systems.

THE IMPORTANCE OF COMMUNITY STRUCTURE

Community structure refers to the relationships among ecosystem components, either physical or functional. Thus, above-ground: below-ground, canopy height or foliage height diversity, clumped or random distribution all refer to spatial relationships among ecosystem components. Interaction among organisms, either in accumulating resources (competition) or in obtaining or providing nourishment (predation), are examples of community structure based on functional relationships. These structural attributes determine many characteristics of ecosystems, including functional capabilities.

On mainlands, or continental areas, patterns of species distributions are less evident, in contrast to the intense and simplified patterns among island organisms. Different habitat types must be considered as equivalent to islands. Such types are spread over large regions in a mosaic configuration and the differences between them, which are emphasized by isolation in island situations, are somewhat obscure. Hypotheses offered to explain variations in diversity of species in continental areas include environmental productivity, climatic stability, predation (including parasitism and disease), and history or opportunities for speciation. MacArthur (1969) believed interspecific interaction to be the major force integrating these concepts. According to this theory, all species will seek to satisfy their requirements for habitat and resources until the region becomes more or less uniformly packed and resource utilization complete. Under these conditions, it is difficult for new species to be added to an area. The number of individuals per species may increase in less productive communities. In productive communities, although the number of species is greater, the number of individuals per species is less. The expansion of number of species in more productive environments is correlated with an increase in morphological variation among the species present (Karr and James 1975).

In the simplified habitats of North American grasslands, the paucity of avian species has been attributed to the irregular occurrence of climatic extremes coupled with the lack of suitable refugia where less tolerant species might survive during periods of climatic extremes (Wiens 1974). In the least productive environments of the world, the deserts, interspecific competition appears to be greater in the more diverse lizard communities. Numbers or species density actually increases with environmental variability. Therefore, the number of species of lizards in a desert habitat seems to be related to the diversity of resources that the lizard community has been able to exploit (Pianka 1975). Desert rodent communities seem to be more diverse than their counterpart lizard communities, perhaps because they represent multiple trophic levels in resource utilization. The number of species present is determined primarily by habitat productivity, while the total rodent density within habitats varies with the amount and predictability of seed resources which vary with precipitation regime.

Hence, there is evidence that primary production and environmental stability, as aspects of community structure, may be important determinants of the kinds and variety of consumers that can exist in a system.

The principal interactions between species that are responsible for structuring communities are competition and predation. Competition occurs when two species utilize the same resource which is in limited supply. Figure 4 ilustrates potential competition along the food niche dimension for some grassland vertebrates. Resource, in this sense, is either nourishment or space. These two types of resources behave differently in their effects on limiting population growth (Wiegert 1974). Competition for a fixed resource such as space results in direct interaction among individuals and is a function of the number of individuals, whereas competition for a renewable resource is a function of the density of that resource and involves indirect interaction among individuals through the resource.

Niche theory is really based on our understanding of competition. This has led to separate definitions of the fundamental niche, which is determined by all possible conditions that enable a species to exist, and the realized niche, which is the proportion of those fundamental conditions that a species succeeds in utilizing in the presence of other species.

Another important population phenomenon that is affected by competition is dispersal. This little-understood process has been attributed to genetic differences in members of populations, but there remains to be discovered experimental evidence to substantiate this hypothesis. Competition is influential in promoting dispersal, either of young away from the territories of adult members of a population or less fit individuals having to seek habitat of marginal value.

Predation is the utilization of one species for nourishment by another. This includes predation on seeds by granivores and predation on plants by herbivores. It has been well demonstrated that changes in plant community composition occur with the addition or removal of grazing herbivores. Herbivores may act directly by removal of particular species or types or indirectly by reducing competitor species which then allows the increase in those types that were previously suppressed by competition. Vertebrate predators may influence competitive relationships of their vertebrate prey species, but they are seldom sufficiently influential to modify existing trophic relationships. The story of eruption of deer (Odocoileus virginianus) populations on the Kaibab Plateau after elimination of mountain lions (Felis concolor) was shown by Caughley (1970) to be erroneous. Probably the only case where a large predator has stabilized an herbivore population that was out of balance is the case of the Isle Royal moose (Alces alces) population. But then, islands are known to be special situations in which certain dynamic relationships are extreme.

The composition of avian communities in grasslands is limited in variety. This recognized fact is attributed to different factors by different investigators. Wiens (1974) believes the true carrying capacity of this habitat is not attained because of periodic and unpredictable fluctuations in climatic conditions which act as a severe stress to the avifauna. Cody (1966) believes these comparatively simple habitats are saturated, thus supporting all of the birds possible. On the other hand, Brown (1973) took an opposite view of climatic instability, and attributed the diversity of seed-eating rodents in sand dune habitats, in part, to the unpredictable nature of desert rains, which determine seed production. Composition of grassland rodent faunas may be determined primarily by structural complexity of the habitat, and secondarily by competitive and behavioral interactions (French et al. 1976).

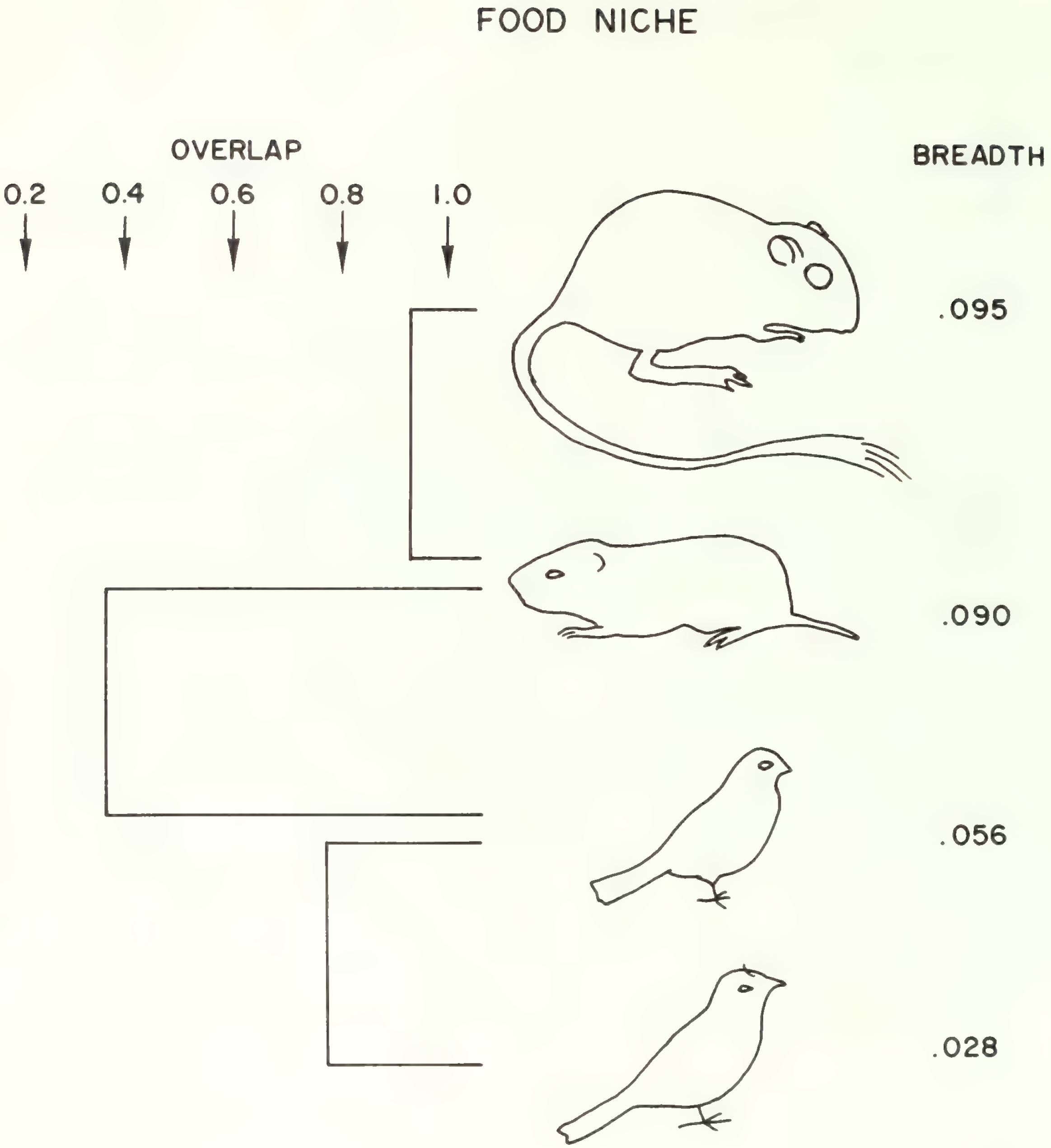


Figure 4. Degree of niche overlap and niche breadth on the food dimension for the kangaroo rat, vole, lark bunting, and horned lark in the shortgrass prairie. The scale of each is from 0 to 1, 1 representing complete overlap or the breadth of the total resource spectrum.

Hence, there is evidence for the importance of primary production, environmental stability, and interspecific interactions in determining the qualitative and quantitative composition of communities. To date, ecology has no set of laws that indicate under what conditions these are relatively more or less important. Therefore, their inclusion in a scheme of habitat classification must be determined by preliminary evaluation of the habitat types under consideration.

TROPHIC PYRAMIDS

That the trophic pyramid concept has achieved the status of a paradigm in ecology is evidenced by the fact that this concept is presented almost without exception in all of the new textbooks that have recently appeared in this field. However, examination and comparison of these presentations indicate that very few examples of ecosystems are sufficiently understood in a quantitative sense to permit their evaluation in the trophic pyramid concept. It is evident that the concept holds true for such divergent systems as grassland, forest, lake, and stream. Even marine systems that are based on plankton production can be fitted into this concept if turnover rate, as well as biomass, is incorporated in the evaluations.

There are several reasons why the trophic levels of an ecosystem are arranged in the shape of a pyramid. This shape is a result of the fact that the material in, or the rate of energy flow through, a given trophic level decreases as it moves through successive steps or transfers within an ecosystem. Transfers between trophic levels are very inefficient. That is, there is incomplete utilization of the food resources harvested. Part of what is harvested is simply not assimilated for use in maintenance and production, and part is simply wasted in the process of harvesting. In addition, each organism of a given trophic level, no matter which trophic level, utilizes a sizable proportion of the energy and material assimilated simply in maintenance of its existing tissue or biomass. Often only a small fraction of this assimilated energy ends up in new tissue, as added biomass in that trophic level available for harvest by the next higher trophic level. Consequently there can be very limited energy available for use by the organisms in the higher trophic categories, which include the predators and particularly the top carnivores of the system. It is axiomatic that their numbers and biomass will be comparatively small.

There is another factor that has an important bearing on the shape of trophic pyramids. This relates to system dynamics. The community that is exporting or losing organic matter at one or more steps in the system transfer processes will have a smaller top, because there is less energy or nutrients to be passed on for the purpose of supporting biomass at the top of the pyramid. Similarly, a system that is storing organic matter in compartments that are large in biomass and slow in turnover rate will also have a smaller top for similar reasons. Thus a watershed which is continually losing matter and nutrients through stream flow which leaves the system will have its structure and function altered accordingly. A system such as a forest which has a large proportion of its biomass stored in the durable large boles of trees will be represented by a pyramid with a very large base and relatively small top.

Utilizing the extensive quantitative data collected by the Grassland Biome Program of the US/IBP, we have constructed and compared biomass trophic pyramids for seven different North American grassland sites. Trophic pyramids representing different types of grassland bear a strong resemblance (Figure 5). There is a very broad base of primary productivity which supports a relatively narrow layer of primary consumers. The magnitude of difference between primary producers and primary consumers is great, considering that detritus feeders are incorporated in these trophic pyramids according to the source of their consumption. The difference between these two levels is much greater than the difference between the secondary consumer level and the base supporting it.

Generally speaking, in the Great Plains, total primary producer biomass is greatest at the tallgrass site and least in the desert grassland. Litter accumulation tends to be higher at the northern sites. The above-ground primary consumer trophic level is predominantly biophagic biomass, while saprophagic biomass is more important below ground. Differences in trophic pyramids between years at the same site are not great, even though wet and dry years are included, in comparison to the differences between grassland types. The difference between grassland trophic pyramids and those of other ecosystems is great (Figure 6).

IMPORTANCE OF CONSUMERS IN ECOSYSTEMS

Trophic pyramid analysis indicated that those for the southern Great Plains tend to be broader based than those for the northern Great Plains. The mountain grassland site is also of the northern type. This indicates a correlation with temperature regime. The fact that the northern trophic pyramids tend to be relatively top heavy suggests the ecosystem function of consumers, as reflected by the biomass, is more important. Perhaps these sites must turn over primary producer biomass at a greater rate, and consumers aid this turnover.

Grant (1974) explored the implications of varying degrees of small mammal activity (Figure 7) in a simulation model depicting consumer interactions and relationships to selected ecosystem functions. His model incorporated augmentation of nutrient cycling by the harvesting and partial wastage of above-ground plant material, the removal of invertebrate consumers by vertebrates, the nutrients added to the soil-plant water relationships by burrowing activities of animals, and alteration of the surface microclimate by the activities of consumers. He demonstrated experimentally that water penetration and soil water-holding capacity are significantly modified by the activities of burrowing animals. The principal modification brought about by this activity, however, is the transport of nutrients from deeper levels in the soil to surface layers where they are available for utilization by plants. Second in importance was the reduction of invertebrate populations brought about by the predatory activities of higher consumers.

In an evaluation of the relative degree of consumption by various animal groups in grassland ecosystems we have reaffirmed that consumers harvest only a minor porcion of the available primary production (French, in press). Invertebrate food material was utilized to a considerable degree at some of the sites, and seeds most likely suffered heavy utilization by consumers. Above-ground invertebrates were the most important consumers at grassland sites, with small mammals sometimes important and birds exerting only minor effects on removal of energy.

The relative importance of various consumer groups to ecosystem function depends not only on their size and/or biomass density but also upon their

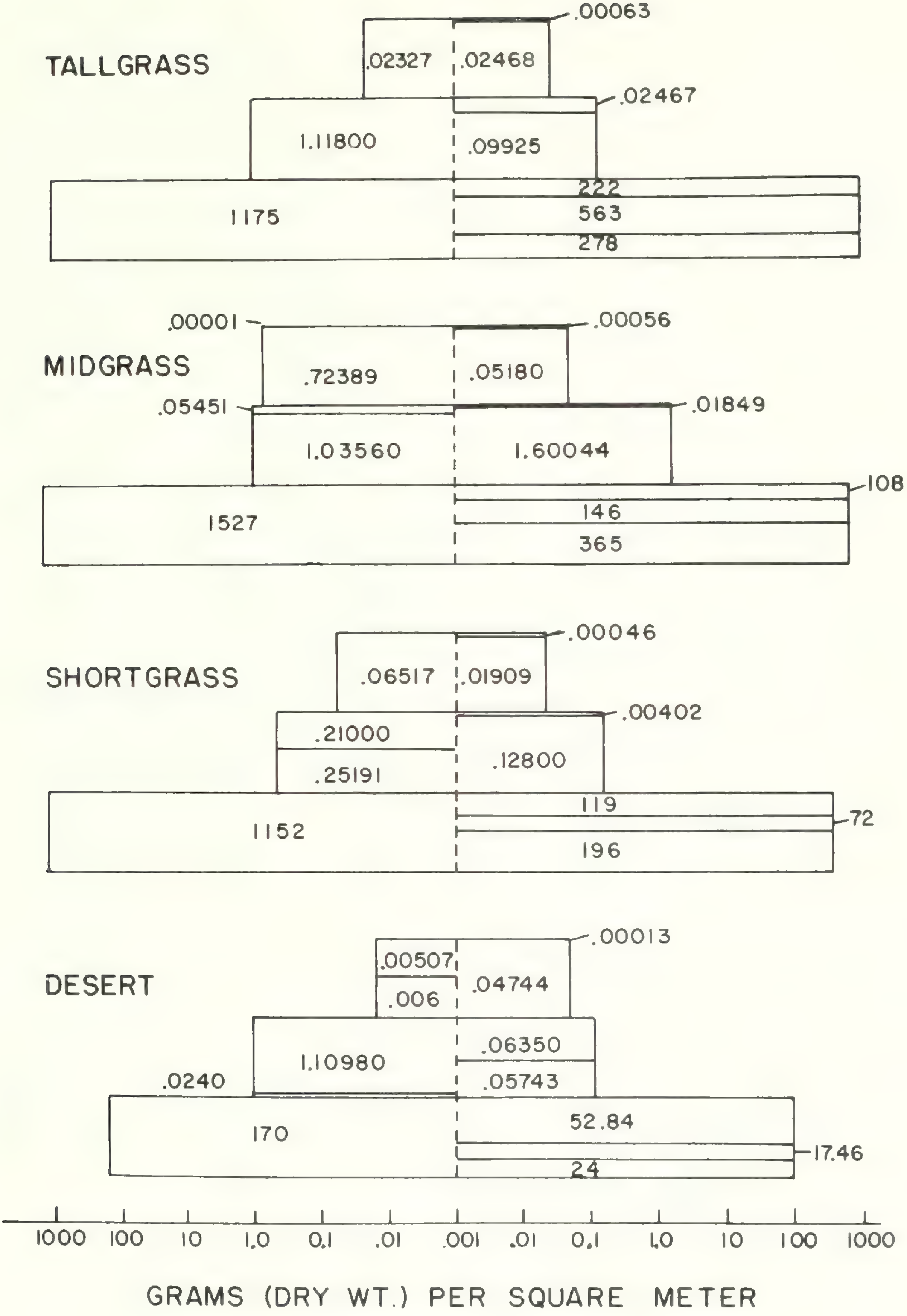


Figure 5. Comparison of trophic biomass pyramids for different grassland sites. (Values presented as in Figure 1).

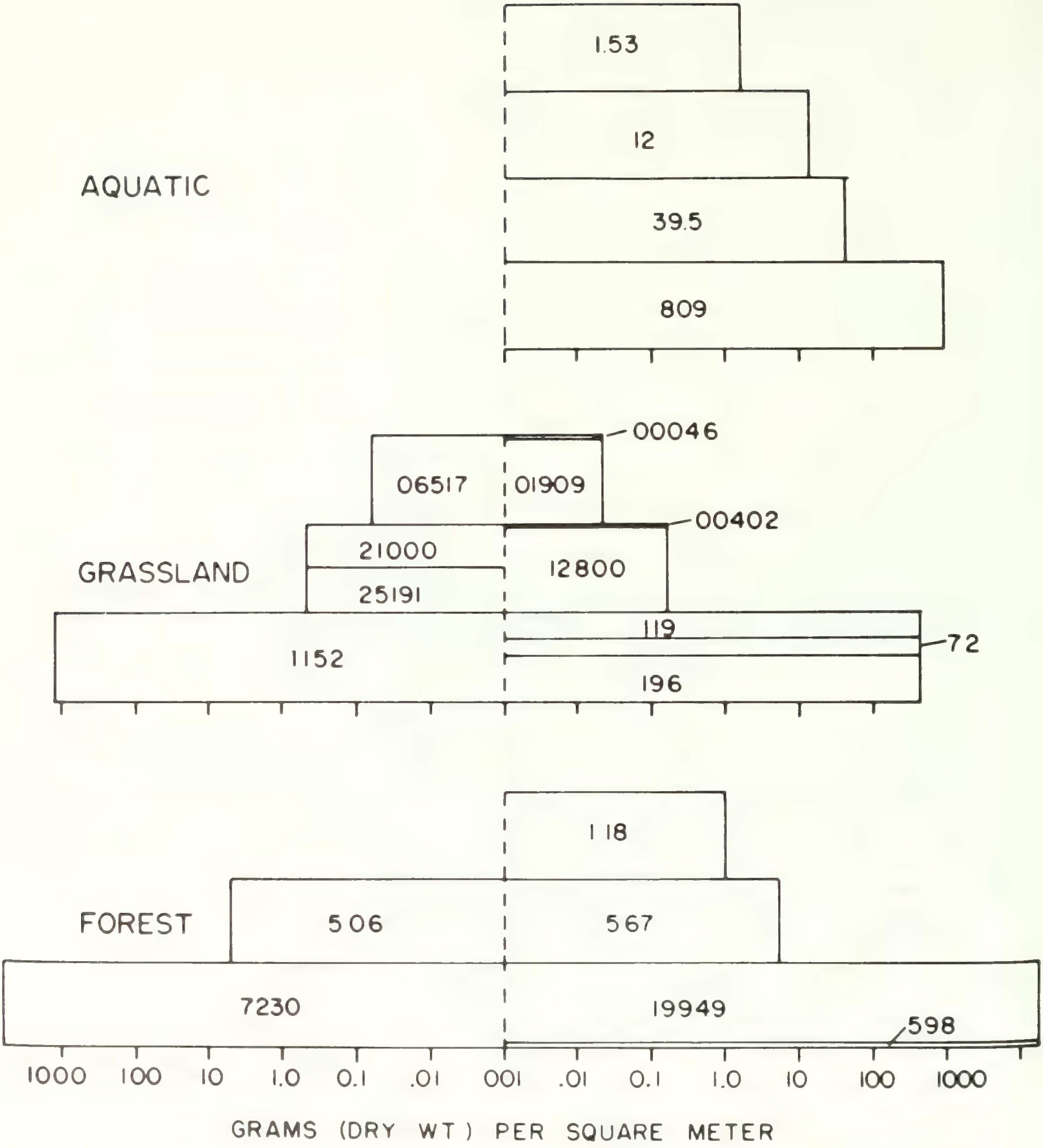


Figure 6. Comparison of trophic biomass pyramids for different ecosystems (aquatic data from Odum 1957, tropical forest data from Odum et al. 1970). The aquatic trophic pyramid is depicted as being entirely above-ground.

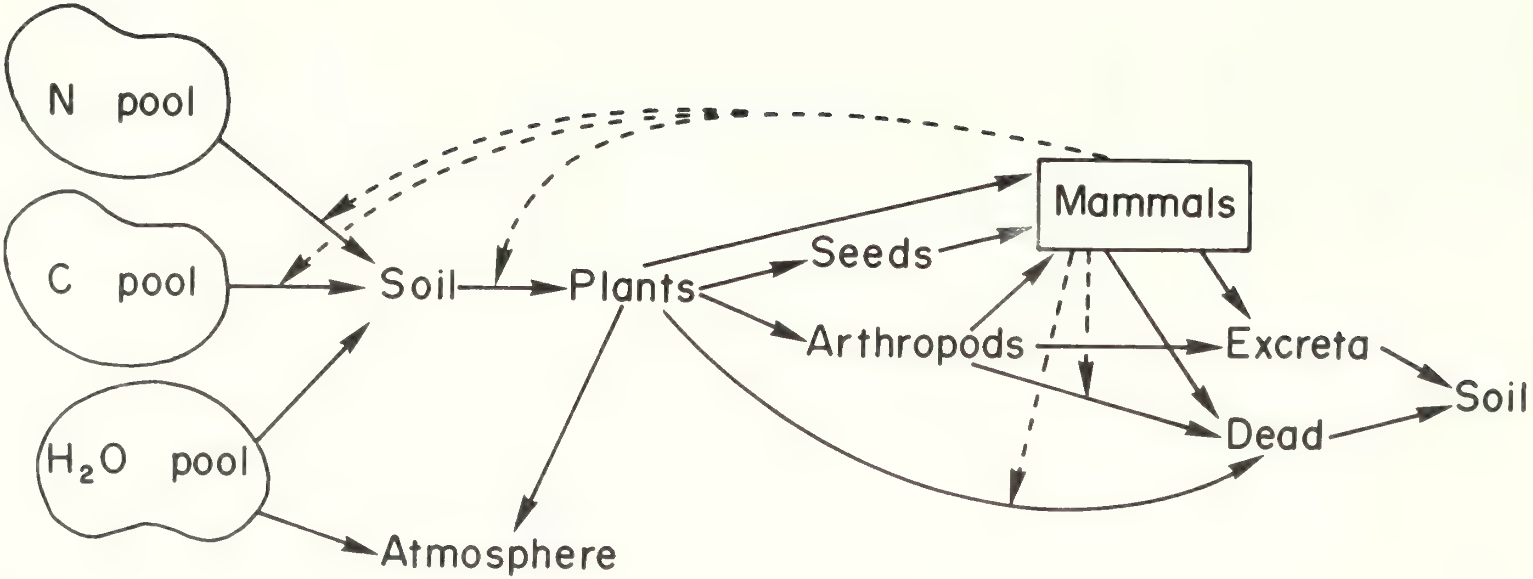


Figure 7. Diagram of computer model that represents interaction of small mammals with ecosystem components and processes (simplified from Grant 1974). Solid lines represent flows; dashed lines represent controls.

efficiency of utilization of harvested energy in production, respiration, and population growth (Table 1). A given biomass of above-ground invertebrate population will consume much more than an equivalent biomass of small mammals or birds because their assimilation efficiency, the energy actually absorbed by the digestive process, is less than half that of the vertebrate consumers. On the other hand, the energy actually assimilated by invertebrates is more efficiently utilized in tissue maintenance and tissue production than in the vertebrate consumers, which expend huge amounts of energy in maintenance processes. As a result of these contrasting characteristics, a given biomass of homeothermic consumers requires far more consumption from the ecosystem for continuation of population processes than does an equivalent biomass of poikilothermic consumers. Homeothermic consumers, therefore, process more primary production material and contribute proportionately more to nutrient cycling of the ecosystem. These consumers can play an important role in augmenting primary production processes if available nutrients are a limiting factor of primary production. (Ecosystem modification experiments indicate that where water is not limiting, nutrients readily are).

KEY FACTORS IN ANALYSIS AND CLASSIFICATION OF HABITAT

Based on the evidence summarized here, there are several characteristics of natural habitats or ecosystems that seem to be important elements in determining the structure of the total system (Figure 8). Numbers or density of organisms provide little information that can be evaluated in the context of structure or function of ecosystems. More useful information is attained when these quantitative values can be presented in terms of biomass or biomass density. Biomass density is itself an important component of the trophic pyramid representing a system, and is the first determination to be made in an evaluation of energy flow through the system. Another factor of importance in classification is the biophagic (grazing food chain) versus saprophagic (detritus food chain) components of the biomass of consumers. Such a classification indicates the relative importance of the two major food chains in the system of consumers. Another factor in classification, that is of importance to understanding the structure of the system, is the vertebrate versus invertebrate components of the system. These last two categories serve to indicate the degree of abiotic control over system and subsystem processes. They also contain information on the comparative efficiency of energy utilization. Similarly the poikilothermic and homeothermic components of the consumer subsystem should enter into the classification. This further indicates the efficiency of energy utilization.

An order of magnitude in refinement of a classification scheme can be obtained if turnover rates of these various components of the consumer biomass can be evaluated. This indicates two important aspects of ecosystem function. This indicates two important aspects of ecosystem function. It is obvious that a greater turnover rate for material in a trophic level indicates a greater rate of energy processing by that level of the system. What is little appreciated, however, is that this rate of turnover is an index of the potential for biomass support at the next higher trophic level in the system. A population of a small prey species that turns over rapidly can support a greater biomass of predators than a population of larger prey species with the same total population biomass that turns over at a lower rate (MacArthur and Connell 1966). It is the production of a population, which represents turnover in a stable population, that determines the energy available to higher trophic levels. For this reason, marine trophic pyramids fail to conform to the

Table 1. Efficiency Comparison (Cost:Benefit) of Heterothermic Consumers (Particularly Insects) and Homeothermic Consumers (Modified from Frenchel 1974)

Category	Homeotherms		Heterotherms
Assimilation	2.3	(benefit)	1
Maintenance	28	(cost)	1
Production	1	(benefit)	24
Population	1.7	(benefit)	1

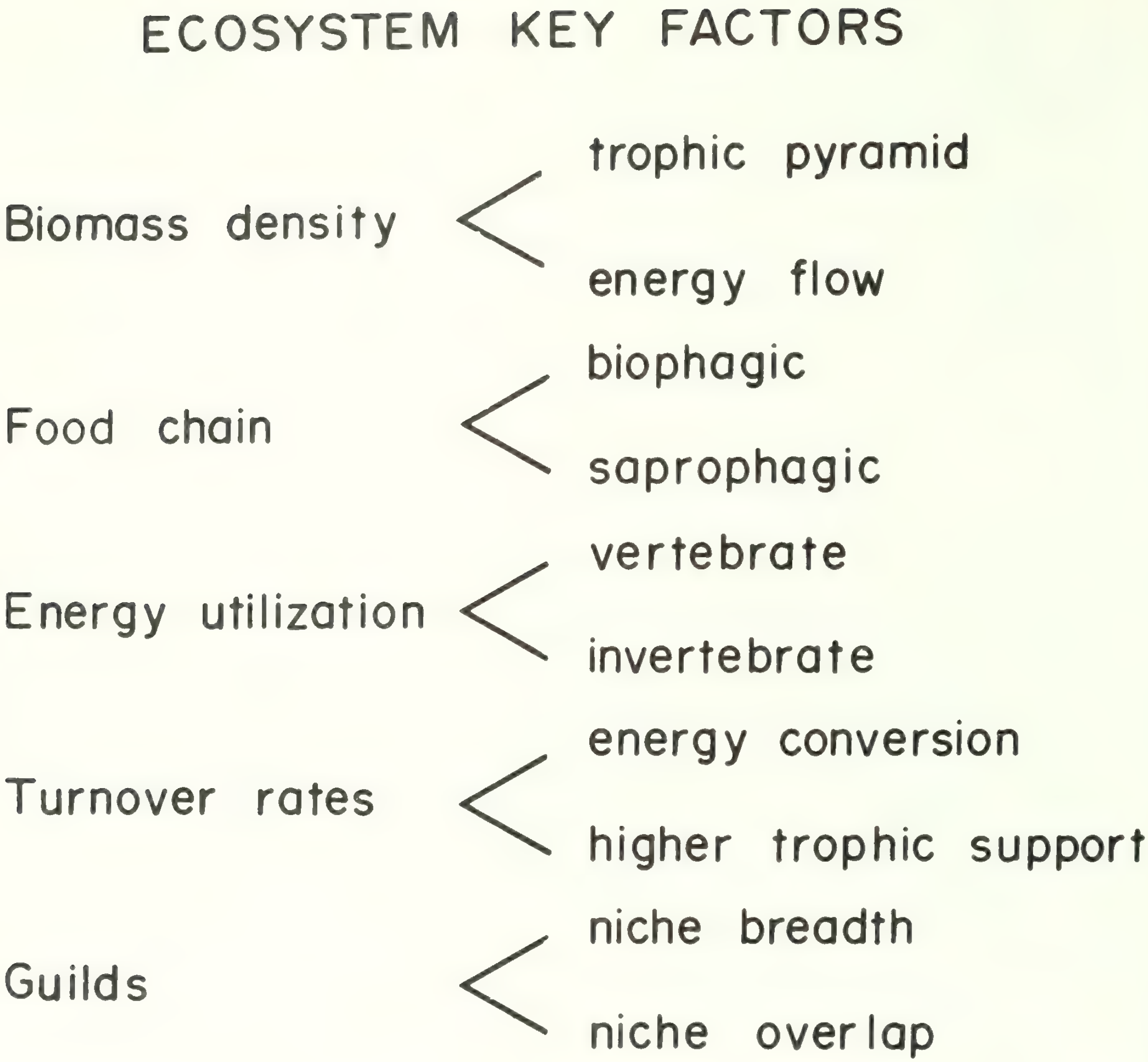


Figure 8. Key factors for ecosystem classification and analysis.

general ecological concept of trophic pyramids because apparently a high concept of trophic pyramids because apparently a high proportion of consumers is being supported by a low biomass of producers. This is possible only because of the extremely high rate of turnover of the plankton providing the main support of the consumer population. LaMotte (1969) has recommended incorporation of turnover rate as one dimension of biomass pyramids.

A useful refinement in the classification can be achieved if organisms are categorized into guilds, and the niche breadth and niche overlap within and between guilds determined to estimate competitive interactions. This has never been achieved for any ecosystem.

ACKNOWLEDGMENTS

This paper reports on work supported in part by National Science Foundation Grant DEB73-02027 A03 to the Grassland Biome, U.S. International Biological Program, for "Analysis of Structure, Function, and Utilization of Grassland Ecosystems."

LITERATURE CITED

Brown, J. H. 1973. Species diversity of seed-eating desert rodents in sand dune habitats. Ecology 54:775-787.

Caughley, G. 1970. Eruption of ungulate populations, with emphasis on Himalayan thar in New Zealand. Ecology 51:53-72.

Cody, M. L. 1966. The consistency of intra- and inter-continental grassland bird species counts. Am. Nat. 100:371-376.

Elton, C. 1927. Animal Ecology. MacMillan Co., New York, New York.

Fenchell, T. 1974. Intrinsic rate of natural increase: The relationship with body size. Oecologia (Berl.) 14:317-326.

French, N. R. (In press). Small mammals as components of the consumer subsystem, In D. P. Snyder (ed.), Populations of Small Mammals under Natural Conditions. Pymatuning Laboratory of Ecology, Univ. Pittsburgh, Linesville.

French, N. R., W. E. Grant, W. Grodzinski, and D. M. Swift. 1976. Small mammal energetics in grassland ecosystems. Ecol. Monogr. 46:201-220.

Grant, W. E. 1974. The Functional Role of Small Mammals in Grassland Ecosystems. Ph.D. Diss. Colorado State Univ., Fort Collins, 179pp.

Grinnell, J. 1917. The niche-relationships of the California thrasher. Auk 34:427-433.

Hutchinson, G. E. 1958. Concluding remarks. Cold Spring Harbor Symp. Quant. Biol. 22:415-427.

Karr, J. R., and F. C. James. 1975. Eco-morphological configurations and convergent evolution in species and communities, pp. 258-291. In M. L. Cody and J. M. Diamond (eds.), Ecology and Evolution of Communities. Belnap Press of Harvard Univ. Press, Cambridge, Massachusetts.

LaMotte, M. M. 1969. Representation synthetique et dynamique de la structure trophique d'un ecosysteme. Comptes Rendus Acad. Sci. Paris 268:2952-2955.

Likens, G. E., F. H. Bormann, N. M. Johnson, and R. S. Pierce. 1967. The calcium, magnesium, potassium, and sodium budgets for a small forested ecosystem. Ecology 48:772-784.

MacArthur, R. H. 1968. The theory of the niche, pp. 159-176. In Population Biology and Evolution. Syracuse Univ. Press, Syracuse, New York.

MacArthur, R. H. 1969. Patterns of communities in the tropics. Biol. J. Linn. Soc. 1:19-30.

MacArthur, R. H., and E. O. Wilson. 1967. The Theory of Island Biogeography. Princeton Univ. Press, Princeton, New Jersey. 203pp.

MacArthur, R. H., and J. Connell. 1966. The Biology of Populations. John Wiley & Sons, Inc., New York, New York. 200pp.

MacArthur, R. H. and E. O. Wilson. 1963. An equilibrium theory of insular zoogeography. Evolution 17:373-387.

Odum, H. T. 1957. Trophic structure and productivity of Silver Springs, Florida. Ecol. Monogr. 27:55-112.

Odum, H. T., W. Abbott, R. K. Sealander, F. B. Golley, and R. F. Wilson. 1970. Estimates of chlorophyll and biomass of the Tabonuco Forest of Puerto Rico, pp. I-3 to I-19. In H. T. Odum and R. F. Pidgeon [ed.], A Tropical Rain Forest. A Study of Irradiation and Ecology at El Verde, Puerto Rico. Div. Tech. Information, USAEC, TID-24270. Clearinghouse for Federal Sci. and Tech. Inf., Natl. Bur. Standards, U.S. Dept. of Commerce, Springfield, Virginia.

Pianka, E. R. 1975. Niche relations of desert lizards, pp. 292-314. In M. L. Cody and J. M. Diamond (eds.), Ecology and Evolution of Communities. Belnap Press of Harvard Univ. Press, Cambridge, Massachusetts.

Reichle, D. E. 1975. Advances in ecosystem analysis. BioScience 25:257-264.

Root, R. B. 1967. The niche exploitation pattern of the blue-gray gnatcatcher. Ecol. Monogr. 37:317-349.

Simberloff, D. S. 1974. Equilibrium theory of island biogeography and ecology. Annu. Rev. Ecol. Syst. 5:161-179.

Wiegert, R. G. 1974. Competition: A theory based on realistic, general equations of population growth. Science 185:539-542.

Wiens, J. A. 1974. Climatic instability and the "ecological saturation" of bird communities in North American grasslands. Condor 76:385-400.

EFFECTS OF THE INSULARIZATION OF THE EASTERN DECIDUOUS FOREST ON AVIFAUNAL DIVERSITY AND TURNOVER

James F. Lynch
Chesapeake Bay Center for Environmental Studies
Smithsonian Institution
Edgewater, Maryland 21037

Robert F. Whitcomb
U.S. Department of Agriculture
ARS, BARCE
Beltsville, Maryland 20705

Abstract: Analysis of breeding bird censuses for isolated tracts of eastern deciduous forest reveals a pattern of general reduction in abundance and diversity of breeding bird species over the past 10 to 20 years. Highly migratory, insectivorous, forest-interior species are most dramatically affected; nearly all species in this group have declined markedly, and many have been extirpated locally. Censuses within larger forested tracts show that such areas are not undergoing the same rapid loss of individuals and species. Species turnover rates are so high in isolated woodlots that important long-term shifts in avifaunal composition and richness tend to be obfuscated by possibly irrelevant short-term colonizations and extinctions by rare or marginal species. Existing urban and suburban parks in the Washington, D.C., area have failed as avifaunal preserves, probably owing to the combined effects of inadequate size, isolation from sources of potential colonists, and increasing levels of disturbance related to human activities. The best hope for preventing the regional extinction of numerous forest-interior bird species in the Atlantic coastal plain and piedmont regions is to reverse the current trend toward insularization of remaining forest.

INTRODUCTION

The possible influence of the geometry of habitat patches on the distribution and abundance of animals is receiving increased attention from theoretical ecologists as well as wildlife managers and conservationists. Some ecologists (e.g., Terborgh 1974, Diamond 1975, Terborgh 1975, Diamond and May 1976, Wilson and Willis 1976) have attempted to apply theoretical precepts derived from the MacArthur-Wilson equilibrium theory of island biogeography (MacArthur and Wilson 1963, 1967) to conservation problems, particularly to the optimization of the design for faunal preserves.

Recently, however, some workers have claimed that such attempts are premature, and have shown that literal acceptance of the MacArthur-Wilson theory in its simplest form actually can lead to conservation strategies that run counter to those generally espoused by those who would justify particular designs for preserves on theoretical grounds (Simberloff 1976a, Simberloff and Abele 1976, Abele and Connor 1978). For example, Simberloff and Abele (1976) suggested that a series of small forest preserves might save more species than a single large reserve of equivalent total area, whereas most earlier workers had reached the opposite conclusion.

Although Simberloff and Abele's tentative suggestion elicited a vigorous response (Diamond 1976, Terborgh 1976, Whitcombe et al 1976), the shortage of empirical data on the effects of insularity on animal communities has prevented any resolution of the controversy. Our goal in the present paper is to present some data concerning long-term shifts in the composition of bird communities in relation to the size, isolation, and level of disturbance to patches of forest habitat.

Over the past 350 years, the nearly continuous expanse of deciduous forest that once blanketed most of the eastern United States has been reduced to an archipelago of forest fragments. Although the total area of forested land remains quite large, most forest on the central coastal plain and adjacent piedmont consists of patches and strips of second growth forest imbedded in a matrix of cropland, pasture, early successional growth, and urban-suburban development. The avifauna associated with the eastern deciduous forest has been studied especially intensively in the area around Washington, D.C., and the voluminous data for this region are currently under review (Whitcomb et al., in preparation). The present paper mainly concerns an analysis of eight data sets, most of which refer to the Washington, D.C. area. Our intent is to direct attention to some of the correlations between habitat insularization and aspects of the structure and dynamics of associated bird communities.

An understanding of species turnover, i.e., the relative frequency of local colonizations and extinctions of species, is especially important in a conservation context, for sequestering an area as a preserve is pointless if the preserved species have high probabilities of rapidly becoming permanently extinct. On the other hand, ecologists gradually have come to accept the notion that local animal populations are dynamic entities subject to finite risks of extinction. By this view, a certain frequency of local extinctions is not necessarily "unnatural", nor even undesirable, providing that adequate opportunities exist for recolonization from external sources of propagules.

The equilibrium theory predicts that the rate of species turnover (here defined as 100 times the sum of extinction plus colonization events per unit time, divided by that sum plus the number of species present throughout the time interval) should increase with increasing isolation of islands, and decrease with increasing island area (Preston 1962, MacArthur and Wilson 1963, 1967). However, the few published relevant data are not fully in accord with these predictions. Thus, Diamond (1969) noted no increase in avifaunal turnover rates with increasing isolation from the mainland, although he did suggest a decrease in turnover rate with increasing island size. However, Simberloff (1976b), detected no consistent relationship between extinction rates and island size in his study of arthropods that inhabit small mangrove islands.

Smith (1975) opined that ecological systems characterized by high frequencies of colonization and extinction are improperly bounded and suggests that ecologists expand their delineation of the limits of apparently turnover-prone systems until turnover is reduced to some acceptably low level. To Smith, high turnover is a signal that the organizing forces of the system are external to it and thus is indicative of poor experimental design by the ecologist. Looking at the turnover problem in a somewhat different (but compatible) way, we can see that high turnover rates are characteristic of local systems that are heavily subsidized by external sources of colonists. Conversely, low rates of extinctions and colonizations might be interpreted as evidence of the organizational stability of a local system.

Regardless of the significance attributed to turnover rates, accurate data on extinctions and colonizations over a long period of time are required. In the absence of such long-term tallies, workers have attempted to estimate annual turnover rates using pairs of widely separated censuses or faunal lists (e.g., Diamond 1969, 1971, Terborgh and Faaborg, 1973). The usual procedure has been to divide the turnover actually observed by the number of years separating the two censuses to obtain an average annual rate. These workers have recognized that a certain number of repeated colonizations and extinctions may have taken place unobserved in the interval between censuses, and that such "cryptoturnover" (sensu Lynch and Johnson 1974) will result in some underestimation of annual turnover rates. Nevertheless, it has been assumed that estimates of mean annual turnover do provide a meaningful approximation of actual yearly rates of colonization and extinction.

METHODS

We have used data from the annual breeding bird censuses published in the journal American Birds (formerly Audubon Field Notes) in our attempt to quantify abundance, community composition, and species turnover for birds of the eastern deciduous forest region. We have focused on the documentation of long-term avifaunal shifts. The general question of the relationship between the size of forest patches and the number of bird species present has been treated elsewhere (e.g., Moore and Hooper, 1975, Galli et al., 1976, Forman et al, 1976) and will be considered here only in passing (see Discussion).

Habitat patches can be classified according to various floristic and physiognomic criteria, but here we will be concerned only with the most general sort of discrimination between mature or maturing deciduous forest and other, mainly nonforested habitat types (agricultural and grazing lands, old-fields, urban-suburban developments, etc.). This sort of classification can be accomplished by means of examination of ordinary aerial photographs, or rapid ground surveys, or both. Our analysis emphasizes communities and guilds (sensu Root, 1967) of ecologically similar avian species, rather than individual species. It can be argued that every bird species is ecologically unique and therefore merits individual attention, and by rejecting this reductionist approach, we certainly have neglected important autecological considerations. We hope, however, that this loss of information is at least partially compensated by documentation of general community patterns that transcend the boundaries of individual species.

We have compiled available bird census data that satisfy the following four criteria.

1) The same plot must have been censused for at least 5 years.

2) The plot must be located at low elevation (less than 500m) in the eastern deciduous forest region.

3) The census plot must be at least 6 ha (15 acres) in size.

4) The plot must be located in reasonably homogeneous mature deciduous forest.

Table 1. Location, Size and Continuity of the Eight Study Sites

Study Site	Location	Plot Size		Continuity
		(acres)	(ha)	
Cabin John Island	Montgomery Co., Maryland	19	8	1947-1976 (except 1950,1955,1969)
Rock Creek Park	District of Columbia	65-80	26-32	1948-1974 (except 1950,1955,1965-7,1970-2)
Glover-Archbold Park	District of Columbia	35	14	1960-1976
Columbia (Upland)	Howard Co., Maryland	30	12	1971-1976
Columbia (Lowland)	Howard Co., Maryland	46	18	1971-1976 (except 1972)
Ann Arbor	Washtenaw Co., Michigan	18	7	1966-1975
Trelease Woods	Champaign Co., Michigan	55	22	1941-1975 (some data to 1927)
Wormsloe	Chatham Co., Georgia	18	7	1963-1973

The first criterion is a minimal requirement for continuity of censusing, if yearly fluctuations in bird populations are to be distinguished from more subtle long-term trends, and in fact census runs of 10 or more years are preferred. Criteria (2) and (4) serve to reduce between-site variation that is attributed to major climatic and vegetational differences. Criterion (3) restricts the analysis to census tracts large enough to permit meaningful calculations of pair densities. Even 6 ha may be too small in some instances, as for example in instances involving large, wide-ranging species or where expansion of census data to a common comparative standard (e.g., pairs/100 acres) is desired. To minimize these potential problems, we omitted very large species from our analysis (see Procedural Conventions). Further, because most of the census tracts we finally considered are wholly or partially isolated discrete forest patches, we view the census data as meaningful indicators of the numbers of birds actually present, at least for smaller species that do not utilize nonforested habitat.

The eight census plots that satisfied all four criteria are listed in Table 1. Of these, Cabin John Island is a completely censused small island in the Potomac River, and is separated by a narrow channel from the adjacent unforested bank. The Wormsloe plot is located within a more extensive forested island (ca 250 ha) that is separated by a few hundred meters of marshland and river from more extensive stands of forest. Rock Creek Park and Glover-Archbold Park are strips of forest bordered by high-density residential areas of Washington, D.C. Trelease Woods and the Ann Arbor tract are rural woodlots surrounded by agricultural land. The Trelease site is the most isolated from similar wooded habitat of any of the plots considered here. Finally, the two plots at Columbia, Maryland, are located within extensive tracts of continuous forest, and therefore serve as "mainland" controls in our interpretation of insular patterns.

There are obvious drawbacks in attempting to analyze diverse census data such as these. The various plots were studied by different workers, and a given plot was in some instances studied by several different investigators over a long period. Intensity of coverage varies from plot to plot and year to year, as do weather conditions during the censusing period. With all of these potential sources of observational inconsistency in mind, one cannot place undue emphasis on the results of any single census, or even on a series of censuses for a given plot. On the other hand, if consistent patterns emerge despite the heterogeneity of the data, we would judge the trends to be relatively robust, in the sense that closer control of observational protocol and elimination of "noise" from the data would only accentuate the patterns.

CLASSIFICATION OF BIRD SPECIES

All species that bred on any of the eight plots at least once were classified as follows:

1) Migratory Status--three categories are recognized: permanent residents (R), short-distance migrants (S), which winter south of their breeding range but north of the tropics, and neotropical migrants (N), which winter in Central or South America, including the Caribbean.

2) Dependence on Non-Forested Habitat--forest-interior species (I) are capable of breeding and foraging regularly in forest, although forest-interior may not be the sole habitat. Edge species (E) require nonforested or forest-edge habitat for at least part of their normal activity during the breeding season.

3) Body Size--"small" species weigh less than 20 g, "medium" species weigh 20-50 g, "large" species weigh 60-149 g, and "very large" species exceed 150 g.

Because birds and their habitats vary continuously and complexly, our simple categorization required some arbitrary decisions, particularly in the distinction between "forest-interior" and "edge" species. For example, we classified the rufous-sided towhee (pipilo erythrophthalmus) as a forest-interior species because it breeds regularly within forest, despite its obvious preference for brushy edges. On the other hand, we considered the brown thrasher (Toxostoma rufum) an edge species because this bird virtually never breeds in the forest interior. Despite such problems of interpretation, our system of classification does focus on important modalities in habitat selection, migratory behavior, and morphology, and once the system is adopted it can be applied uniformly to diverse data sets.

PROCEDURAL CONVENTIONS

It soon became evident that a few ground rules needed to be adopted for interpretation of the census data. First, we decided to omit "very large" species from consideration. Such species typically range over areas that are large relative to the size of a census plot, making even their presence or absence, much less their effective density, difficult to establish. All of the computations that follow refer only to bird species that average less than 150 g in body weight.

A second decision was that the "+" designation, frequently used by censusers to indicate that a small fraction of a species territory extends onto the census plot, is too ambiguous to permit a confident assessment of breeding status and density of individuals. Accordingly, a "+" entry in the census data was considered equivalent to "missing data," and the status of the species in question was considered unchanged from the previous year. Thus, a "+" record did not constitute sufficient evidence of colonization if it followed a year when the species was absent altogether. On the other hand, the "+" designation was interpreted as evidence that the species was still present on the plot if a definite breeding presence had been documented in the previous breeding season. This convention served to eliminate considerable "noise" from the data set, and did not greatly affect the number of extinctions and colonizations tallied over a long run of censuses, except where species repeatedly disappear from a plot and reappear only at the "+" level of abundance. Such "in-and-out" appearances were relatively uncommon, and in any event are of dubious ecological or evolutionary significance (Smith 1975, Simberloff, 1976a).

RESULTS

ABUNDANCE AND DIVERSITY

Overall Abundance of Breeding Birds

Data for the census plots with the longest runs of censuses show no strong trends in bird abundance through the 1950's and 1960's, although year-to-year fluctuations in numbers frequently exceed 20 percent. Beginning in the early 1970's, however, a general decline in abundance is evident in all five plots for which comparable data are available for the previous decade (Table 2). Declines range from an insignificant 2 percent in Trelease Woods to about 45 percent in Rock Creek Park and Wormsloe.

Number of Breeding Species

This figure also shows considerable variation from one year to the next, but the data indicate a gradual reduction in species richness that began at least as early as the early 1960's, and that has continued to the present. Again, all five plots with 10 or more years of census data shown a decline in mean species abundance between the 1960's and 1970's (Table 2), the reduction ranging from 3-20 percent of the original species total over a 10-year interval. The three plots that have been studied for 20 years or more have lost 14-24 percent of the original complement of species over a 20-year period.

Neotropical Migrants

The long-term disruption of avifaunal composition in isolated wooded tracts becomes even more evident when bird species are grouped into migratory categories. About 75 percent of the bird species that breed in the contiguous United States migrate to the tropics during the nonbreeding season (Welty 1962) and most species associated with the primordial eastern deciduous forest fall into this highly migratory group. Exceptions tend to be relatively large nonpasserines (e.g., woodpeckers, hawks, owls), although some small passerines (e.g., parids, nuthatches) are permanent residents or short-distance migrants. On the other hand, "edge" species, which must have been much less common prior to the disruption of the eastern deciduous forest region by European man, tend to be either permanent residents or short-distance migrants.

Table 2 and Figure 1 show clearly that it is the neotropical migrant species, most of which are small- to medium-sized passerines, that have undergone the most drastic reductions in abundance and diversity over the past quarter century. As examples, we can cite Cabin John Island, which experienced a mean decline of nearly 50 percent in the number of neotropical migrant birds between 1951-56 and 1971-76, or Rock Creek Park, for which the equivalent figure is a staggering 78 percent. Considering all eight census plots, there are eight 10-year intervals over which population levels of neotropical migrant species can be compared. All eight comparisons reveal a decline in both the absolute and relative abundance of long-distance migrant species. The probability of eight such declines occurring by chance is less than 0.01 by the sign test.

Table 2. Mean Number of Species, Individuals, Permanent Residents + Short-distance Migrants (R+S), Neotropical Migrants (N), and Percent of Total Population Made up of Neotropical Migrants Averaged Over 5-Year Intervals for the Eight Study Sites

		Locality							
Category	Census Interval	Cabin John	Rock Creek	Glover Archbold	Columbia (Upland)	Columbia (Lowland)	Ann Arbor	Trelease Woods	Wormsloe
Mean Number of species	1951-56	27.0	24.4(5)					35.8(6)	
	1961-66	24.1	25.0(4)	31.5(6)				29.3(6)	20.0(4)
	1971-76	20.5	21.0(2)	25.3(6)	26.5(6)	37.2(5)	22.2(5)	28.4(5)	15.3(3)
Mean Number terr. males	1951-56	117.1	166.7					157.0	
	1961-66	109.7	154.2	186.6				212.5	84.4
	1971-76	89.6	85.5	182.2	87.2	193.9	42.2	161.0	45.3
Mean Number (R+S)	1951-56	39.8	25.5					93.5	
	1961-66	49.5	48.8	126.0				170.2	36.8
	1971-76	49.9	55.0	146.4	32.9	96.5	26.4	132.0	27.5
Mean Number (N)	1951-56	77.3	141.2					63.5	
	1961-66	60.2	105.4	60.6				42.3	47.6
	1971-76	39.7	30.5	35.7	54.3	97.4	15.8	29.0	17.8
Mean Percent (N)	1951-56	66	85					40	
	1961-66	55	68	32				20	56
	1971-76	44	36	20	62	50	37	18	39

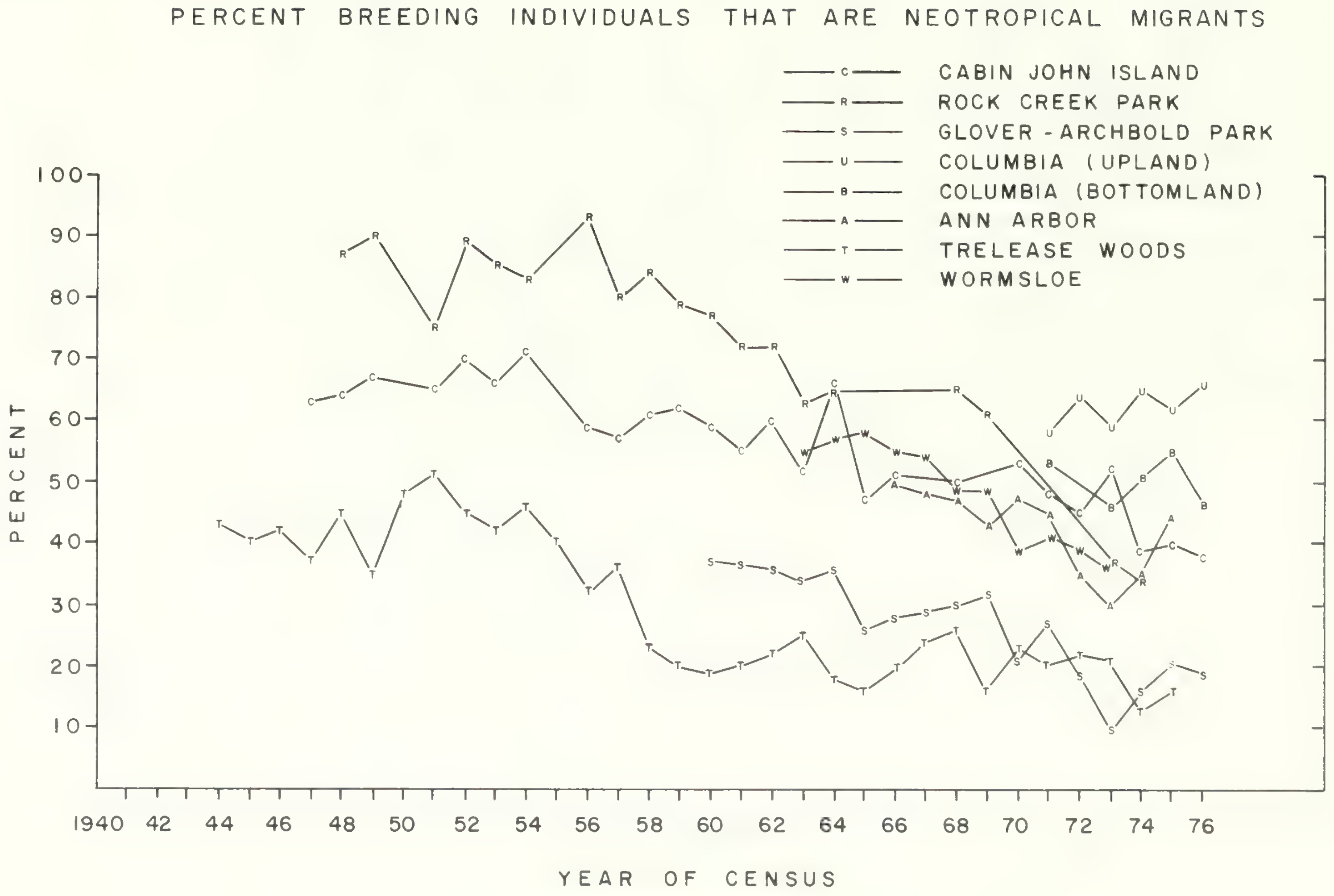


Figure 1. Relative decline in abundance of neotropical migrant individuals in the avifaunas of isolated woodlots as a function of time. At present, the two "mainland" plots at Columbia Maryland have the highest proportion of neotropical migrants.

Permanent Residents and Short-Distance Migrants

The three plots with the longest runs of censuses all showed an increase in the number of breeding resident and short-distance migrant species in the 1960's. However, this increase only partly compensated for the decline in numbers of neotropical migrant birds. The permanently resident species and short-distance migrants that breed in wooded tracts tend to be either "edge" species not normally associated with forest-interior, or species nominally included in our "forest-interior" category despite their clearcut preference for edge and other disturbed habitat (e.g., rufous-sided towhee, common flicker, Colaptes auratus). The few bona fide forest-interior species that are also permanent residents are mostly bark-foragers or omnivores (e.g., downy woodpecker Picoides pubescens, hairy woodpecker Picoides villosus, white-breasted nuthatch Sitta carolinensis, tufted titmouse Parus bicolor, carolina chickadee Parus carolinensis).

The abundance of resident and short-distance migrant species has leveled off or even declined in the present decade, but because the neotropical migrants have declined even more markedly, the relative importance of the former two migratory groups has continued to increase.

Warblers and Vireos

This assemblage of small, insectivorous, highly migratory species exemplifies the kinds of temporal trends that have affected the forest-dwelling neotropical migrants as a group. As documented in Table 3 and Figure 2, warblers and vireos have declined dramatically in all areas for which we have long-term census data. For example, during the late 1940's and early 1950's, Cabin John Island supported regular breeding populations of seven warbler species: American redstart (Setophaga ruticilla), common yellowthroat (Geothlypis trichas), hooded warbler (Wilsonia citrina), Kentucky warbler (Oporornis formosus), Louisiana waterthrush (Seiurus motacilla), parula warbler (Parula americana), prothonotary warbler (Protonotaria citrea). By 1976 all but the American redstart and prothonotary warbler had become locally extinct. Even the American redstart was present at only about one-third its previous density, and this species too seem destined for extirpation. Similarly, at nearby Rock Creek Park four of five formerly breeding warbler species have disappeared and the remaining species (Ovenbird, Seiurus aurocapillus) has suffered a reduction in abundance of more than 80 percent.

Trelease Woods, by virtue of its extreme and longstanding isolation from potential sources of colonists, provides an example of the ultimate fate of the avifauna of isolated forest fragments. By the early 1940's Trelease Woods already was the most depauperate of the eight study sites with respect to warblers and vireos. Only the common yellowthroat, an "edge" species, and the red-eyed vireo (Vireo olivaceus) have bred there regularly since the 1950's; the latter is now present at about one-third its former breeding density.

The red-eyed vireo may be the most characteristic small, insectivorous, highly migratory bird species that inhabits the eastern deciduous forest. The species breeds on all eight of the census plots considered here, and is capable of reaching densities approaching one pair/acre. It is therefore significant that the red-eyed vireo has declined in abundance on all plots for which long-term data exist.

Table 3. Mean Number of Territorial Male Vireos and Warblers Averaged Over 5-Year Intervals for the Eight Study Sites

		Locality							
Species	Time Interval	Cabin John	Rock Creek	Glover Archbold	Columbia (Upland)	Columbia (Lowland)	Ann Arbor	Trelease Woods	Wormsloe
Red-eyed vireo	1951-56	15.2	37.8					18.3	
	1961-66	14.0	31.4	9.5				4.0	7.4
	1971-76	10.3	7.3	8.4	13.2	11.1	4.8	4.6	3.8
Warbles & other vireos	1951-56	32.8	79.0					0.7	
	1961-66	22.8	68.4	24.8				0.2	27.1
	1971-76	13.2	18.2	2.1	14.2	40.2	1.3	0.0	9.0
Total warbles & vireos	1951-56	48.0	116.8					19.0	
	1961-66	36.8	99.	34.3				4.2	34.5
	1971-76	23.6	25.5	10.5	27.4	51.3	6.1	4.6	12.8

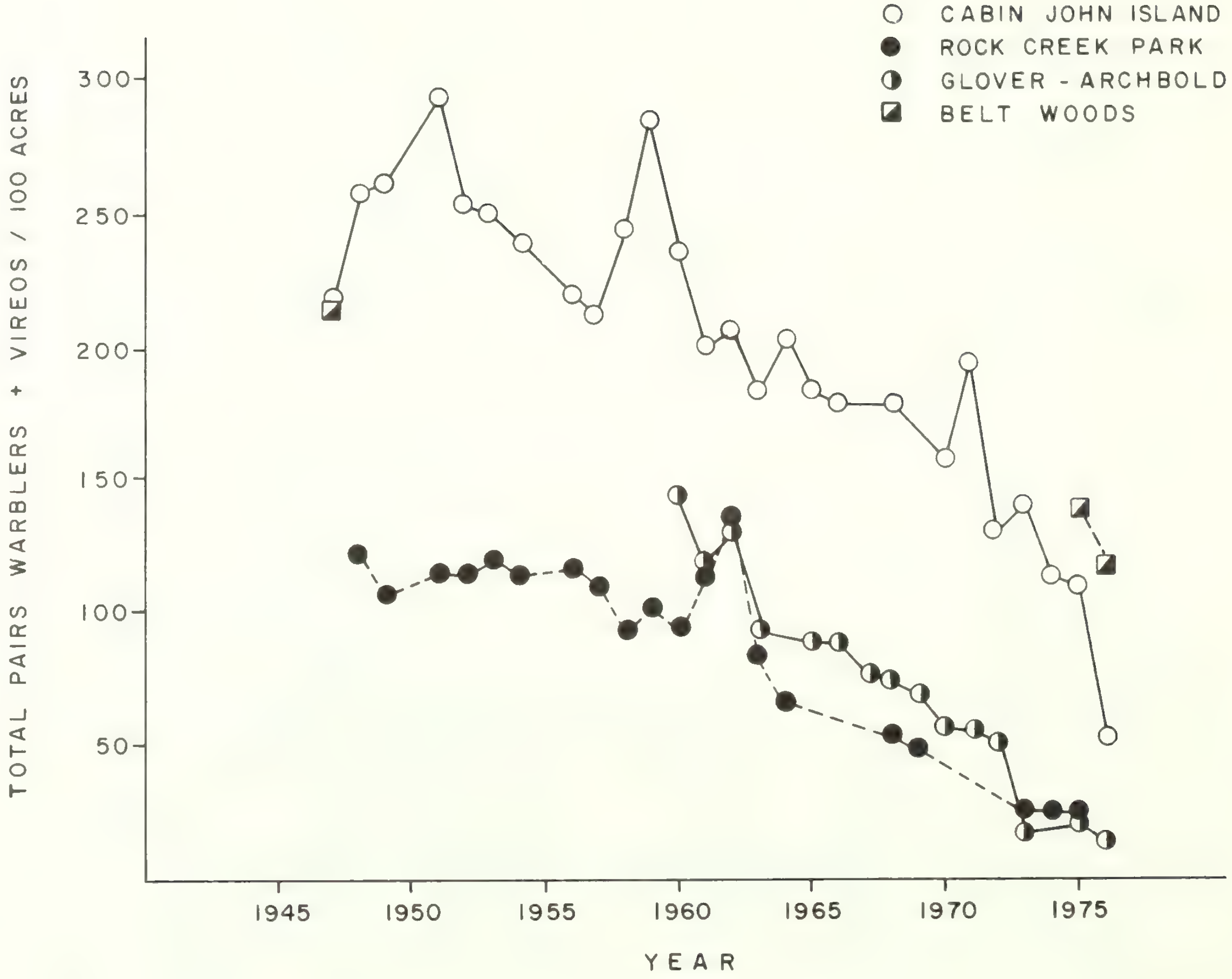


Figure 2. Decline in total abundance of warblers and vireos at three isolated wooded tracts in the Washington, D.C., area. Three censuses for Belt Woods in nearby rural Maryland are shown for comparison.

The majority of warbler species and vireos other than the red-eyed vireo already have been extirpated in the fragmented areas studied. The reduction in numbers of breeding pairs in this assemblage over the last decade ranges from 42 percent (Cabin John Island) to 92 percent (Glover-Archbold Park). At Trelease Woods this entire group of species became extinct in the early 1970's, but their abundance in the previous decade was already so low (average of about 0.2 breeding pairs per year) that total extirpation required only a minor further reduction in abundance. Only in the two "mainland" plots at Columbia, Maryland, do warblers and vireos appear to be holding their own. Unfortunately, census data for these two sites go back only to 1971, and we have no way of knowing whether abundance and diversity were even higher in earlier years.

Flycatchers

Eastern deciduous forests from the middle Atlantic region southward typically are inhabited by three species of flycatchers (Tyrannidae): great crested flycatcher (Myiarchus crinitus), eastern wood pewee (Contopus virens), and Acadian flycatcher (Empidonax virescens). All three have bred on the eight census plots, but, like the warblers and vireos, show a general pattern of declining numbers over the last two decades (Table 4). As a group, flycatchers have been reduced in numbers by 22 percent (Cabin John Island) to 90 percent (Rock Creek Park) since the early 1960's. The continued survival of the Acadian flycatcher as a breeding species is unlikely in five of eight plots, the exceptions being the two "mainland" plots at Columbia and the Cabin John Island site. The prognosis is little better for the great crested flycatcher, and even the ubiquitous eastern wood pewee is extinct or nearly so on three of the plots.

ANNUAL SPECIES TURNOVER

Magnitude and Variability of Turnover

Annual turnover of species has been computed separately for forest-interior species, for edge species, and for all species combined (Table 5). Species turnover is unexpectedly high, despite the conservative bias introduced by our decision to ignore "very large" species and "+" records of breeding activity, and variation between years at a given site is extreme. The median annual turnover rate for 15 6-year intervals among the various study plots ranges from 8-37 percent (it should be noted that the method of computing turnover used by Diamond (1969) involves dividing the number of colonizations and extinctions by twice the number of species in the total pool; Diamond's method thus will yield turnover rates about half as large as ours). Significantly, the lowest turnover is found for the Columbia lowland plot in the middle of a large, continuous expanse of forest. The highest median turnover rate is that at Wormsloe, Georgia, the site with the fewest species of birds present. Year-to-year variation at a single site is so great (Figure 3) that one cannot generalize about typical turnover patterns on the basis of a single turnover computation.

Relevance of Turnover Rates to Long-Term Trends

The data tend to support Smith's (1975) view that excessively high rates of extinction and colonization may obscure the important organizational features in a local system. All five study sites with long-term records have experienced a loss of species and individuals over the past decade or more, but we see only a hint of this destabilization when we compare turnover rates

Table 4. Mean Number of Territorial Male Flycatchers Averaged Over 5-Year Intervals for the Eight Study Sites

Species	Time Interval	Locality							
		Cabin John	Rock Creek	Glover Archbold	Columbia (Upland)	Columbia (LowLand)	Ann Arbor	Trelease Woods	Wormsloe
Great crested flycatcher	1951-56	2.8	2.5					4.2	
	1961-66	2.8	3.4	3.6				6.2	1.4
	1971-76	1.3	0.2	1.3	0.2	0.8	1.3	3.6	0.5
Eastern wood pewee	1951-56	3.4	6.2					16.0	
	1961-66	2.5	5.4	2.8				9.7	2.2
	1971-76	1.9	0.2	0.6	1.8	4.6	3.4	6.2	0.3
Acadian flycatcher	1951-56	9.2	18.5					0.3	
	1961-66	10.2	15.8	8.9				0.2	0.8
	1971-76	9.2	2.0	2.2	8.8	17.7	0.9	0.0	0.7

Table 5. Median Annual Turnover Rate Computed Over 5-Year Intervals for the Eight Study Sites. Turnover is Computed as $\frac{I + E}{I + E + P} \times 100$, Where I=Number of Species that Immigrated to the Plot Between Censuses, E=Number of Species that Went Extinct, and P=Number of Species that Persisted Through Both Censuses

Time Interval	Locality							
	Cabin John	Rock Creek	Glover Archbold	Columbia (Upland)	Columbia (Lowland)	Ann Arbor	Trelease Woods	Wormsloe
1951-56	13	19					27	
1961-66	17	14	15				19	18
1971-76	16	25	22	17	8	21	23	37

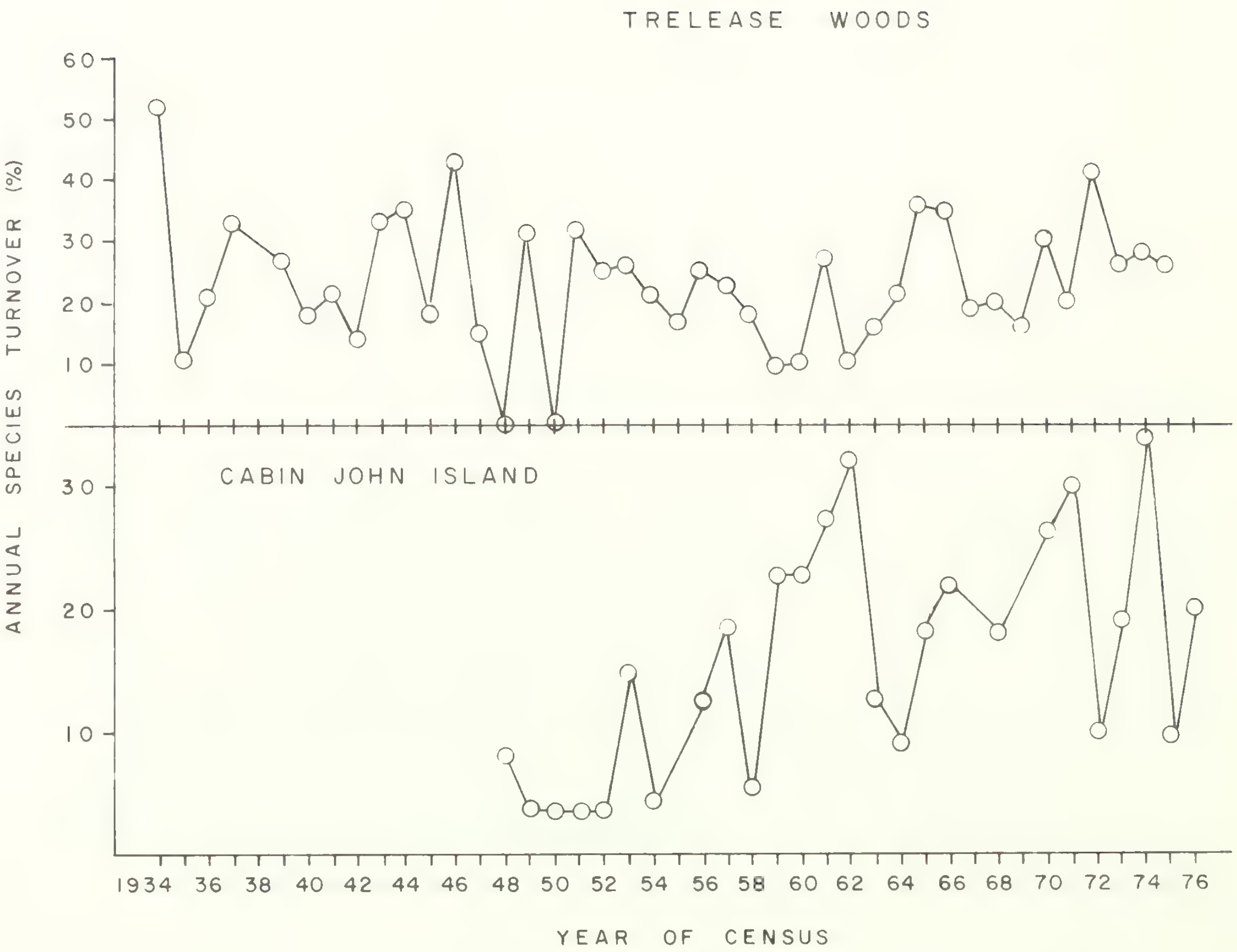


Figure 3. Annual percent species turnover for Trelease Woods and Cabin John Island. Note different scales on the ordinates. Turnover is highly variable from one year to another. The apparent increase in mean turnover rate in recent years at the Cabin John Island site may be related to the removal of woodland habitat from the adjacent mainland in the early 1950's.

in the 1950's, 1960's, and 1970's (Table 5). In two of three cases, median turnover rates are higher in the 1950's than in the 1960's, although yearly variation is too high to permit a statistically significant differential. In one case turnover rates are actually marginally lower in the present decade than in the previous one, despite the accelerating decline in diversity and abundance in recent years.

The problem is that the number of ephemeral colonizations and extinctions by species that never become very common on the plots is sufficiently high to obscure the gradual pattern of declining species richness. The manner in which turnover is computed dictates that the appearance of a single breeding pair of a previously absent species, followed by the disappearance of that species the next year, will count twice as much in the turnover computation as will the steady decline to extinction of a species (such as the ovenbird or red-eyed vireo) that was initially codominant.

A specific example may help to clarify the relationship between annual turnover dynamics and long-term ecological shifts. The mean number of breeding species on Cabin John Island declined from 27.0 in the period 1951-1956 to 20.5 in 1971-1976. Surely a reduction of 25 percent in the number of species is ecologically important, even disregarding additional changes in the identities of breeding species. Nevertheless, the average net excess of extinctions over colonizations during this time interval was only about six species, whereas the grand total of extinction and colonization events over the same period was 74! By currently accepted criteria (e.g., Abbott and Grant 1976), the approximate balance of extinctions (40) and colonizations (34) would be considered as evidence for existence of a state of equilibrium, but such an interpretation is surely false in view of the evidence presented above. In fact, the avifauna of Cabin John Island, and most other sites considered here, is undergoing both a reduction in overall species richness and a systematic replacement of specialized neotropical migrant birds by more generalized permanent resident and short-distance migrant forms.

Relationship Between the Size and Isolation of Forest Fragments and Annual Turnover Rates

We have examined too few sites to allow a quantitative partitioning of the effects on species turnover rates of patch size vs. isolation vs. intensity of disturbance. Turnover is so variable from year to year that large numbers of plots would have to be surveyed if the various potential effects were to be disentangled in a statistically meaningful manner. There does appear to be a weak negative correlation between median annual turnover rate and mean number of breeding bird species ($r = -0.50$), though the significance level at $n =$ eight sites exceeds 0.05. The correlation is mainly determined by the two extreme cases (Wormsloe with 15.3 species and median turnover rate of 37 percent per year and the Columbia bottomland plot with 37.2 species and 8 percent turnover) and the six intermediate cases show no particular trend.

The Effect of Long Inter-Census Intervals on Computed Turnover

Data for the three sites with 20 or more years of censuses (Cabin John Island, Rock Creek Park, and Trelease Woods) can be used to estimate the effects of elapsed time on computed turnover rates. As noted above, perhaps the most important feature of annual species turnover at a given site is the enormous variation betweeen years (Figure 4). Only where large numbers of yearly censuses are available can a meaningful mean or median figure for

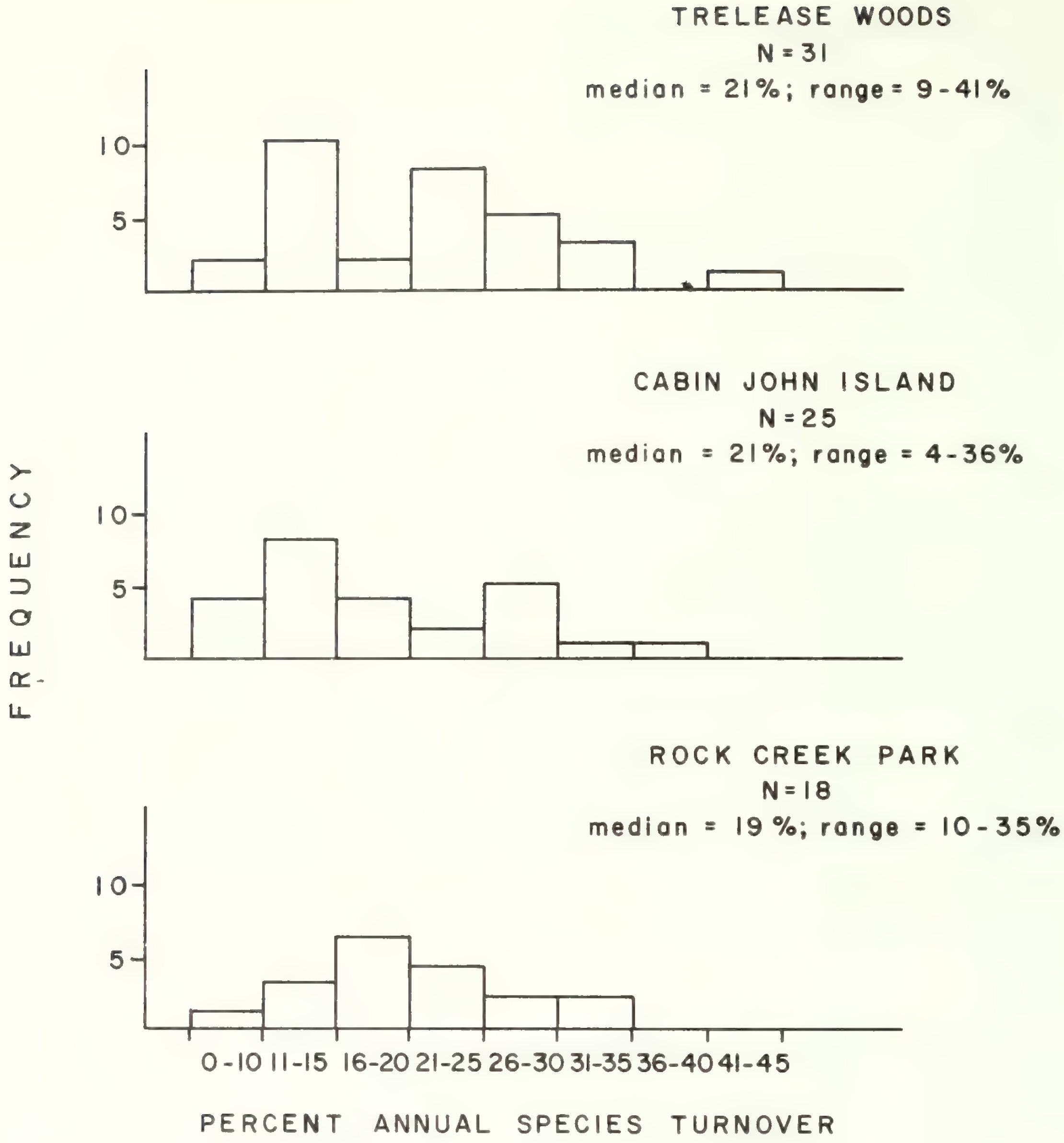


Figure 4. Histograms plotting frequency of various annual turnover rates for the three sites with the longest continuity of census data. The extreme variability at a given site makes it difficult to compare rates between areas or to characterize normal turnover rates at a given site.

annual turnover be calculated. Even in these cases the variance is so large that comparisons between sites are difficult.

The true annual turnover rate would be underestimated by about 90 percent if apparent turnover per 20 years were simply divided by 20 to get an annual rate (Figure 5). Thus, "cryptoturnover," attributed to repeated colonizations and extinctions by individual species during the interval between censuses, is too high to permit straightforward calculation of annual turnover from widely spaced censuses. Apparent turnover does increase with the time interval between censuses, but at a decreasing rate (Figure 6). Both Rock Creek Park and Cabin John Island appear to approach an asymptotic value of apparent turnover at $t_2-t_1 = 20$ years, and for both sites that asymptote is less than twice the turnover observed at $t_2-t_1 = 1$ year. Trelease Woods has not approached an asymptotic turnover value after 20 years, an indication that the avifauna of this tract is continuing to shift composition directionally. However, the apparent turnover over 20 year intervals is still only about 2.5 times the figure for 1-year intervals.

If extinctions and colonizations occur randomly, i.e., if there is not a directional change in avifaunal composition, apparent turnover should theoretically approach an asymptote with increasing intervals between censuses. The rate at which this asymptote is approached will depend on the amount of cryptoturnover in the system; if probabilities of repeated colonizations and extinctions are high, then cryptoturnover will be high, and the asymptote will be approached rapidly. Conversely, low probabilities of extinction and colonization will result in an accumulation of faunal changes over short runs of censuses, and approach to an asymptotic apparent turnover rate will be slower. If turnover reflects nonrandom systematic replacement of species, as where a "climax" assemblage of bird species is superseded by "weedy" species normally associated with earlier seral stages of vegetation, an asymptote will not be approached until the replacement has been completed. The latter possibility may apply to Trelease Woods.

DISCUSSION

It has been documented elsewhere (Bond 1957, Moore and Hooper 1975, Galli et al. 1976, Forman et al. 1976) that bird species differ in the minimal area of habitat they require for successful breeding and foraging. Importantly, there appear to be no bird species that are restricted to small habitat patches, although there are many that occur only in larger patches. This relationship is highly relevant to the design of avifaunal preserves, for it means that not only will some bird species not utilize small preserves, but also that there will not be any species unique to small preserves.

Furthermore, those bird species that do persist in small forest patches, such as those studied by Forman et al. (1976), tend to fall into our "edge" category or to be the most edge-loving of our "forest-interior" group. Most are permanent residents or short-distance migrants and are graminivorous or omnivorous in their feeding habits. In contrast, the area-sensitive species that are restricted to larger forest patches tend to be the same small- to medium-sized, insectivorous neotropical migrant, forest-interior species shown in the present study to be heavily impacted in isolated, disturbed forest tracts.

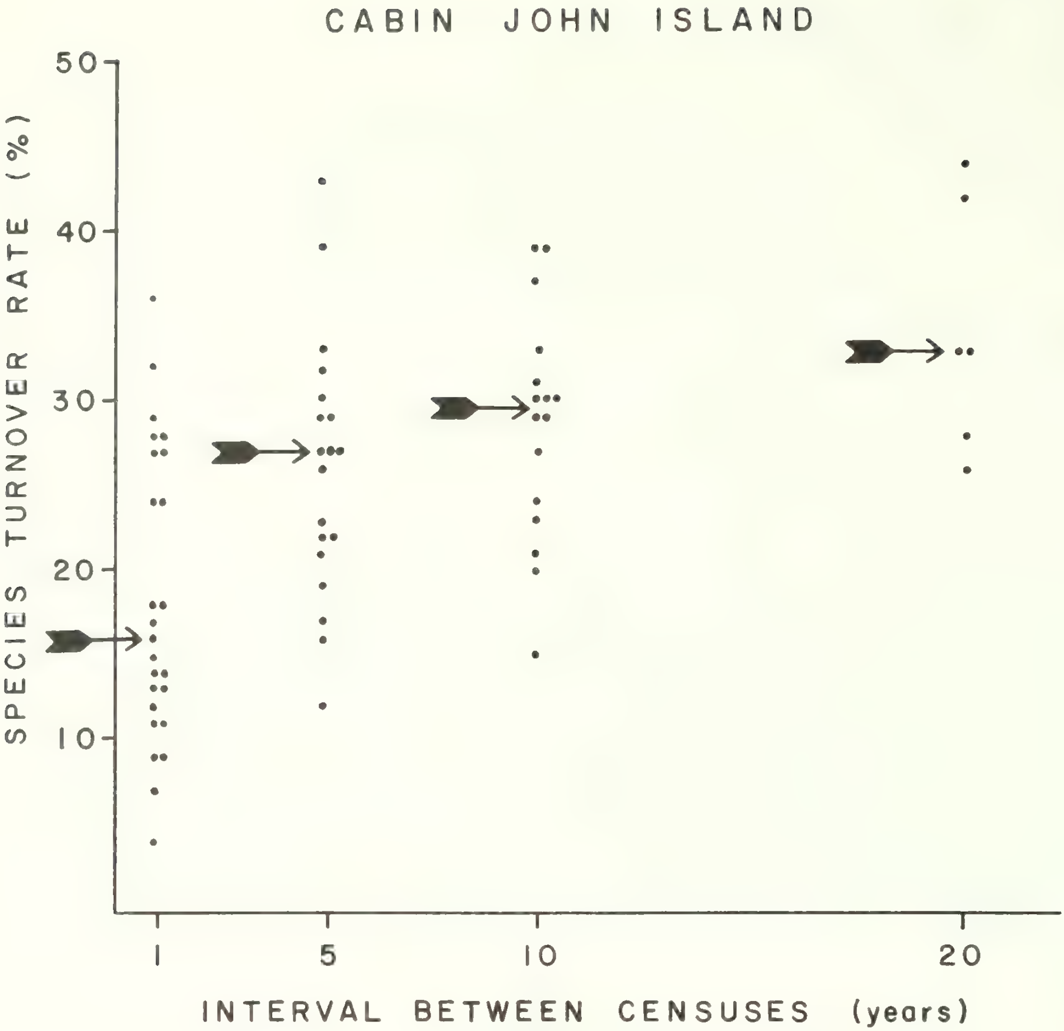


Figure 5. Species turnover as a function of the interval between censuses. Each point represents a pairwise comparison of censuses separated by 1, 5, 10, or 20 years. Arrows indicate median turnover value for a given time interval.

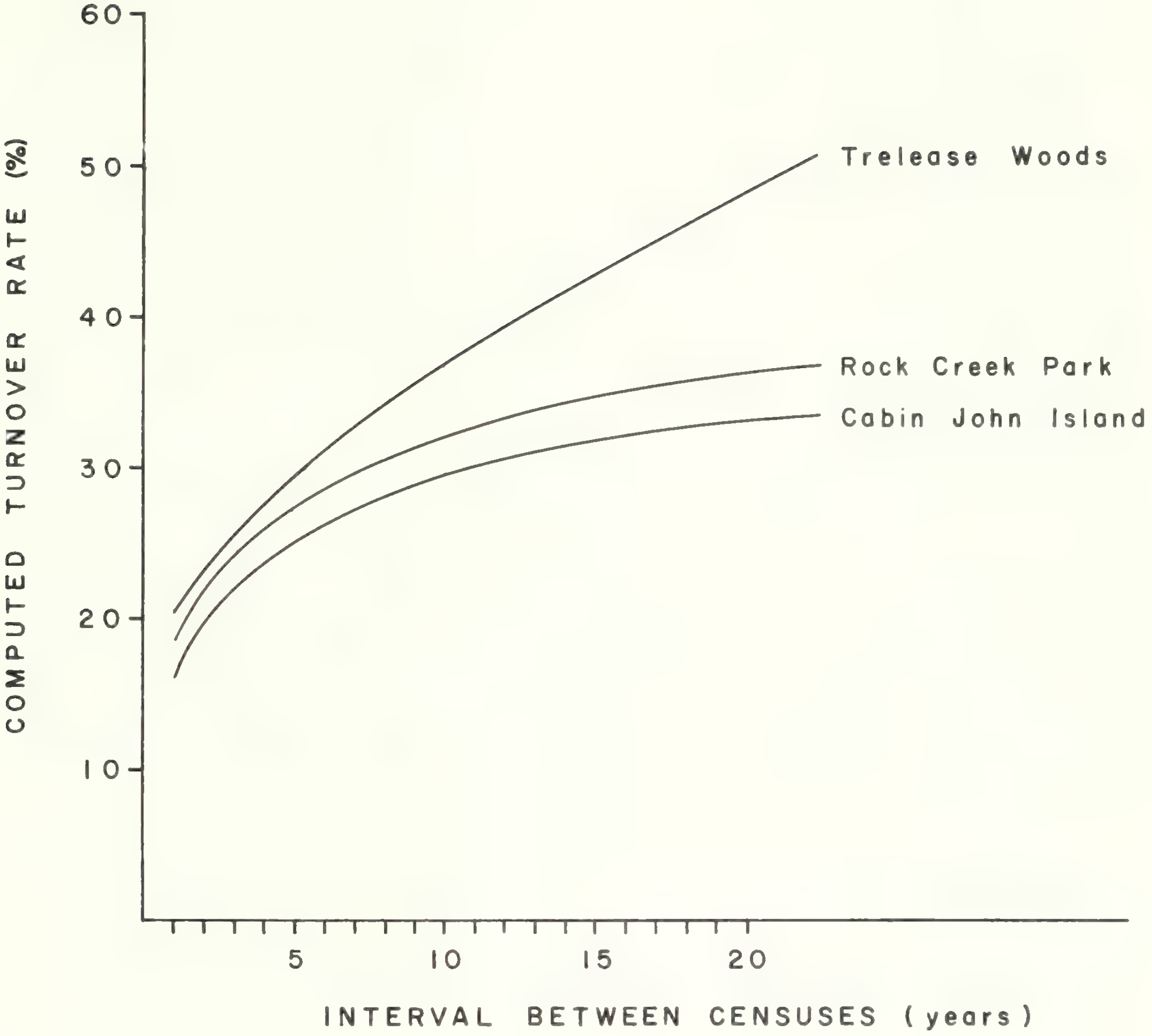


Figure 6. Smoothed curves plotting median turnover rate as a function of interval between censuses for the three plots with the longest continuity. Rock Creek Park and Cabin John Island show similar turnover rates, and appear to approach an asymptotic turnover value at intervals longer than 20 years. Trelease Woods shows somewhat higher turnover, and has not approached an asymptote after 20 years.

That area per se, as opposed to increasing habitat diversity, plays an important role is suggested by the findings of Galli et al. (1976), who showed that no correlation exists between foliage height diversity and patch size for a group of New Jersey woodlots. The important point to be made, then, is that *no number of small woodlots can possibly contain all the bird species capable of breeding in larger woodlots*.

Simberloff and Abele (1976) suggest that series of small preserves might be preferable to setting aside one or a few large preserves of the same total area, but their suggestion ignores interspecific differences in area requirements and extinction-colonization probabilities. In our view there is simply no substitute for large preserves of the order of thousands of hectares if the full range of bird species is to be included. It is conceivable, however, that several preserves, each with an area of thousands of hectares, might preserve more species than a single preserve that comprises the same aggregate area. This scale is, of course, much larger than that relevant to real conservation planning in the eastern United States.

The present study contributes an additional insight into the species-area relationship, namely that area-sensitivity is not fixed for a given bird species and habitat. Instead, the responses of birds to patch size appear to shift in response to changes in other factors, particularly degree of isolation and intensity of disturbance. Without the perspective provided by long-term census data, one might conclude that the regional parks in the Washington, D.C. area are simply "too small" to support stable breeding populations of most forest-interior bird species. Given the present degree of isolation and intensity of disturbance in such parks, such a conclusion may be valid, but it ignores the fact that many of the presently missing species bred regularly in these same parks for many years. We therefore interpret the observed avifaunal deterioration as a response to regional patterns of destruction and fragmentation of mature deciduous forest and to increasing levels of human-related disturbance within the censused tracts.

As long as extensive wooded areas persist nearby, even small parks and woodlots may preserve a semblance of a normal forest-interior community of birds, although the most area-sensitive species will be absent, and there will be a tendency for "edge" species to invade. Such a situation is, however, inherently unstable, because populations of most species in small woodlots will be so low that continual immigration of individuals from external habitat is required if local extinction of populations is to be avoided. Thus, small reserves always must be subsidized by larger ones if normal species assemblages are to persist in the former.

During the first half of the present century a trend toward reforestation of abandoned farmland characterized some portions of the eastern seaboard of the United States. At present, however, this trend has been reversed in many areas, and urbanization and suburbanization are making significant inroads in the maturing second-growth forest. As avifaunal immigration rates fall, and they surely must under conditions of shrinking availabiltiy of habitat, the only factor that could prevent loss of species in forest patches would be a corresponding decrease in extinction rates.

The latter trend is of course highly unlikely in the face of the multitude of stresses that actually *increase* the probability of local extinctions in small, isolated forest tracts. For breeding birds some of these stresses would include: trampling of understory vegetation, repeated disturbance of nesting and feeding birds, predation by cats and dogs, competition for food and nest sites with native and introduced "edge" species that tend to invade forest patches, increased levels of brood-parasitism by the edge-loving brown-headed cowbird (Molothrus ater), and increased levels of pollution by noise, light, and toxic chemicals. All of these potentially detrimental influences tend to co-occur in urban and suburban parks, and it is virtually impossible to sort out their individual effects on bird populations, or to separate disturbance phenomena as a group from the geometrical properties of size and isolation of habitat patches.

There is a tendency among ecologists to think of terrestrial habitat patches as being somehow less insular than "true" islands (i.e., those surrounded by water) from the point of view of mobile organisms such as birds. While it is true that dispersal between terrestrial habitat patches may be easier than between true islands, the pressures of insular existence may, in fact, be more severe for many species in the terrestrial situation, particularly in an urban or suburban setting. For birds on oceanic islands, the surrounding waters are important mainly as a passive barrier to immigration and emigration, whereas for birds in urban parks the surrounding sea of humanity generates a diverse and ever-intensifying barrage of predators, competitors, pollutants, and other disruptive influences.

There is room for disagreement as to the relative importance of area vs. isolation vs. human disturbance as determinants of avifaunal diversity, species composition, and turnover, but there is no denying the failure of small forested tracts as meaningful reserves for the forest-interior avifauna of eastern North America. Only large, continuous blocks of forest, such as those sampled by the two Columbia, Maryland, census plots, appear capable of maintaining a normal complement of forest-interior species at reasonable densities.

The contrast between a relatively intact avifauna and one which has been severely truncated by insularization is graphically illustrated by the data gathered by one of us (RFW) on the relative density of birds in an extensive forested tract of over 4,000 ha on the Beltsville Agricultural Research Center, as compared with densities in an adjacent portion of the same forest which has been dissected from the main tract by roads. The smaller tract, which presently is a part of Greenbelt Park in Prince Georges County, Maryland, is actually quite extensive (ca. 150 ha) compared to the eight plots treated in the present paper, but construction of a highway, smaller roadways and footpaths, and sewer facilities, combined with a greatly increased intensity of human visitation, has drastically affected the avifauna of this tract (Table 6).

Six of the 15 forest-interior neotropical migrant species encountered in the larger tract were absent from ecologically similar sites in Greenbelt Park, and 7 of the 9 species held in common were less abundant at the latter site. There were no forest-interior neotropical migrant species found in Greenbelt Park that did not also occur on the Beltsville tract. In contrast, the abundance of permanently resident and short-distance migrant bird species tended to be as high or higher in Greenbelt Park. Again, this illustrates the general tendency for more sedentary birds to be more effective than the neotropical migrants at utilizing disturbed and ecotonal habitats.

In the case of Greenbelt Park, isolation from potential sources of colonists is clearly less of a factor than is the intensity of disturbance. The existing maze of roads, trails, powerlines, and sewer rights-of-way effectively subdivide the park into a cluster of still smaller fragments, within which many bird species cannot persist.

Table 6. Indices of Abundance of Birds at Eight Points in Greenbelt Park and at Similar Points in the Nearby Extensive Forest at the Beltsville Agricultural Research Center (BARC). Indices of Abundance are Numbers of Perceived Territories per Point

Category	Greenbelt Park	BARC forest
Forest-interior neotropical migrants		
Yellow-billed cuckoo (*Coccyzus americanus*)	0.20	0.44
Ruby-throated hummingbird (*Archilochus colubris*)	0	0.20
Great Crested flycatcher (*Myiarchus crinitus*)	0.40	0.55
Eastern wood pewee (*Contopus virens*)	0.65	0.62
Wood thrush (*Hylocichla mustelina*)	2.05	1.60
Blue-gray gnatcatcher (*Polioptila caerulea*)	0	0.20
Yellow-throated vireo (*Vireo flavifrons*)	0	0.40
Black-and-white warbler (*Mniotilta varia*)	0.30	0.75
Pine warbler (*Dendroica pinus*)	0.50	1.22
Ovenbird (*Seiurus aurocapillus*)	1.25	2.63
Louisiana waterthrush (*Seirus motacilla*)	0	0.20
Kentucky warbler (*Oporornis formosus*)	0	0.50
Hooded warbler (*Wilsonia citrina*)	0	0.82
Scarlet tanager (*Piranga olivacea*)	1.05	1.35
Red-eyed vireo (*Vireo olivaceus*)	1.40	1.66
Short-distance migrants		
Mourning dove (*Zenaida macroura*)	0	0.36
Common flicker (*Colaptes auratus*)	0.50	0.32
Eastern phoebe (*Sayornis phoebe*)	0	0.06
Blue jay (*Cyanocitta cristata*)	+	+
Gray catbird (*Dumetella carolinensis*)	0.20	0.10
Brown thrasher (*Toxostoma rufum*)	0.20	0.12

Table 6 (Concluded)

Category	Greenbelt Park	BARC forest
Short-distance migrants (Cont'd.)		
Robin (*Turdus migratorius*)	0.95	0.17
Eastern bluebird (*Sialia sialis*)	0	0.50
Common grackle (*Quiscalus quiscula*)	0.50	0.12
Brown-headed cowbird (*Molothrus ater*)	1.10	0.30
American goldfinch (*Spinus tristis*)	0.55	0
Rufous-sided towhee (*Pipilo erythrophthalmus*)	2.05	1.08
Permanent residents		
Bobwhite (*Colinus virginianus*)	1.00	0.17
Pileated woodpecker (*Dryocopus pileatus*)	0	0.18
Red-bellied woodpecker (*Centurus carolinus*)	0.65	0.98
Hairy woodpecker (*Picoides villosus*)	0	0.36
Downy woodpecker (*Picoides pubescens*)	0.75	0.40
Carolina chickadee (*Parus carolinensis*)	0.80	0.90
Tufted titmouse (*Parus bicolor*)	1.60	1.70
White-breasted nuthatch (*Sitta carolinensis*)	0	0.75
Carolina wren (*Thryothorus ludovicianus*)	1.85	1.10
Starling (*Sturnus vulgaris*)	0	0.07
Cardinal (*Richmondena cardinalis*)	0.85	0.75

We have confined most of our discussion to eight long-term censuses, but additional relevant data exist, particularly for the Washington, D.C., area. In all, more than 100 each of breeding bird survey routes, bird censuses, and point surveys have been undertaken by various ornithologists in the Washington metropolitan region, and three local counties have been covered by Breeding Bird Atlas projects. This supplementary information supports our conclusions, based mainly on data for the two Columbia plots, that large forested tracts are not suffering the same drastic loss of species and individuals observed in smaller tracts.

As an example, we can cite the results of a comparison of the avifauna of the Seton Belt tract, Prince Georges County, Maryland, between the year 1947 and the years 1975 and 1976 (Whitcomb et al., 1977a; Whitcomb et al., 1975, 1977b). The Belt tract is a mature stand of exceptionally rich tuliptree-oak forest that supports an abundant and varied avifauna. Although the tract is of moderate size (ca 40 ha), it is partially connected with a much larger forest system containing woodlots of 100-200 ha and is bordered by agricultural land rather than urban or suburban settlement. Relative to the 1947 census, the 1975-76 data show a definite reduction in numbers in most neotropical migrant species (Figure 2), including the disappearance of the worm-eating warbler (Helmitheros vermivorus) and black-and-white warbler, but these declines were of a lesser magnitude than those observed in Rock Creek Park, Cabin John Island, and Glover-Archbold Park over the same interval.

The red-eyed vireo, for example, remained at extremely high density. Even the two species that have disappeared from the Belt tract proper are present in the adjacent woodland, so that the forest system as a whole has maintained the 1947 species composition. Species known from our other studies to be especially size-sensitive in their habitat requirements (e.g., hooded warbler, Kentucky warbler, parula warbler, ovenbird, Acadian flycatcher) all are abundantly present in and near the Belt tract.

Although we lack continuous long-term census data for plots within large forested tracts, individual censuses from such areas reveal the continuing presence of area-sensitive forest-interior species. As an example, the Beltsville Agricultural Research Center forest, referred to in the earlier discussion of Greenbelt Park, is part of an interconnected forest system of over 4,000 ha and supports an avifaunal community that, in composition and density, closely resembles the assemblage present in Rock Creek Park during the late 1940's (Whitcomb et al. 1975, MacClintock et al. 1976). Point surveys by one of us (RFW) indicate that, with the possible exception of the worm-eating warbler, all area-sensitive bird species that would be expected in this part of Maryland do breed in the Beltsville forest.

SUMMARY AND CONCLUSIONS

We are led inescapably to the conclusion that regional extinction of many bird species associated with eastern deciduous forest is inevitable unless large areas of forest are sequestered. In view of the prohibitive cost of suitably large acreage of private lands, the only real hope is that existing tracts of public land can be so managed as to serve as avifaunal reserves. In this connection, it should be emphasized that the size and level of disturbance of such potential reserves is more important than the details of their vegetational composition. Most forest-interior species appear capable of utilizing mid-successional forest and a large tract of such forest may be a better avifaunal preserve than a smaller tract of more mature woods.

Turning to the Washington, D.C. area for a specific example of the kinds of opportunity for avifaunal preservation that still exist close to major urban centers, we can cite the thousands of hectares of land in central Maryland administered by the U.S. Department of Agriculture, the U.S. Fish and Wildlife Service, the Department of the Army, the National Aeronautical and Space Agency, and various State and municipal park services. The larger of these land holdings are contiguous and therefore have the potential for serving as a significant regional avifaunal preserve. (Committee of Biologists for Preservation of Natural Areas, 1976.)

As long as due consideration is given to the preservation of the continuity of the existing forest through intelligent placement of roads, trails, sewers, powerlines, etc., such areas can serve an increasingly important conservation role while at the same time continuing to fulfill the primary functions for which they are operated. Without such planning, fragmentation and disturbance of the remaining forested habitat will increase and the result will be the irretrievable loss of a unique portion of the regional biota.

Summarizing, we have shown the following:

1. Birds breeding in small isolated forest tracts in the eastern United States have experienced a general decline in abundance and species richness over the past few decades. This avifaunal deterioration appears to be an inevitable sequel to the insularization of forested habitat.

2. The birds most severely affected are forest-interior species that migrate to the neotropical area during the nonbreeding season. Many species in this group have declined to local extinction and nearly all show marked reductions in abundance compared to levels observed in earlier years.

3. Existing urban and suburban parks are unsuccessful as avifaunal reserves, probably as a result of their combination of small size, increasing isolation from sources of potential colonists, and high level of human-related disturbance.

4. Extensive forested tracts are not experiencing the rapid loss of species and individuals observed in smaller tracts.

5. Species turnover rates in small isolated forest fragments are so high that ecologically significant long-term shifts in species composition and diversity tend to be obscured by possibly irrelevant short-term colonizations and extinctions by marginal species.

6. These trends are best documented for the area around Washington, D.C., but the same pattern appears to hold for forest fragments in Illinois, Michigan, and Georgia. This suggests that the trends characterize the entire eastern deciduous forest region.

7. The best hope for prevention of numerous regional extinctions of forest-interior bird species along the Atlantic coastal plain is to halt and, ideally, to reverse the present trend toward insularization of remaining forested land.

LITERATURE CITED

Abbott, I., and P.R. Grant. 1976. Non-equilibrial bird faunas on islands. Am. Nat. 110:507-528.

Abele, L.G., and E.F. Connor. 1978. Application of island biogeography theory to refuge design: making the right decision for the wrong reason.

Bond, R.R. 1957. Ecological distribution of breeding birds in the upland forests of southern Wisconsin. Ecol. Monogr. 27:351-384.

Committee of Biologists for Preservation of Natural Areas. 1976. Beltsville Federal Masterplan Area: Biological and Research Values and Recommendations for Land Use Master Planning. Prince Georges Audubon Soc.

Diamond, J.M. 1969. Avifaunal equilibria and species turnover rates on the Channel Islands of California. Proc. Natl. Acad. Sci. 64:57-63.

Diamond, J.M. 1971. Comparison of faunal equilibrium turnover rates on a tropical island and a temperate island. Proc. Natl. Acad. Sci. 68:2742-2745.

Diamond, J.M. 1975. The island dilemma: lessons of modern biogeographic studies for the design of natural reserves. Biol. Conserv. 7:129-146.

Diamond, J.M. 1976. Island biogeography and conservation: strategy and limitations. Science 193:1027-1029.

Diamond, J.M., and R.M. May. 1976. Island biogeography and the design of natural reserves, pp. 163-186, in May, R.M. (ed.), Theoretical Ecology: Principles and Applications. W.B. Saunders Co., Philadelphia.

Forman, R.T.T., A.E. Galli, and C.F. Leck. 1976. Forest size and avian diversity in New Jersey woodlots with some land-use implications. Oecologia 26:1-8.

Galli, A.E., C.F. Leck, and R.T.T. Forman. 1976. Avian distribution patterns within different sized forest islands in central New Jersey. Auk 93:356-365.

Lynch, J.F., and N.K. Johnson. 1974. Turnover and equilibria in insular avifaunas with special reference to the California Channel Islands. Condor 76:370-384.

MacArthur, R.H., and E.O. Wilson. 1963. An equilibrium theory of insular zoogeography. Evolution 17:373-387.

MacArthur, R.H., and E.O. Wilson. 1967. The Theory of Island Biogeography Princeton Univ. Press, Princeton, New Jersey. 203 pp.

MacClintock, L., R.F. Whitcomb, and B.L. Whitcomb. 1977. Island biogeography and "habitat islands" of eastern forest. II. Evidence for the value of corridors and the minimization of isolation in preservation of biotic diversity. Am. Birds 31:6-16.

Moore, N.W., and M.D. Hooper. 1975. On the number of bird species in British woods. Biol. Conserv. 8:239-250.

Preston, F.W. 1962. The canonical distribution of commonness and rarity. Ecology 43:185-215; 410-432.

Root, R.B. 1967. The niche-exploitation pattern of the Blue-gray gnatcatcher. Ecol. Monogr. 37:317-350.

Simberloff, D. 1976a. Species turnover and equilibrium biogeography. Science 194:572-578.

Simberloff, D. 1976b. Experimental zoogeography of islands: effects of island size. Ecology 57:629-648.

Simberloff, D., and L.G. Abele. 1976. Island biogeography theory and conservation practice. Science 191:285-286.

Smith, F.E. 1975. Ecosystems and evolution. Bull. Ecol. Soc. Am. 56:2-6.

Terborgh, J. 1974. Presentation of natural diversity: the problem of extinction-prone species. Bioscience 24:715-722.

Terborgh, J. 1975. Faunal equilibria and the design of wildlife preserves, pp. 369-380. in Golley, F.B., and E. Medina (eds.), Tropical Ecological Systems: Trends in Terrestrial and Aquatic Research. Springer-Verlag, New York.

Terborgh, J. 1976. Island biogeography and conservation: strategy and limitations. Science 193:1029-1030.

Terborgh, J., and J. Faaborg. 1973. Turnover and ecological release in the avifauna of Mona Island, Puerto Rico. Auk 90:75-79.

Welty, J.C. 1962. The life of birds. W.B. Saunders Co., Philadelphia.

Whitcomb, B.L., R.F. Whitcomb, and D. Bystrak. 1977a. Island biogeography and "habitat islands" of eastern forest. III. Long-term turnover and effects of selective logging on the avifauna of forest fragments. Am. Birds 31:17-23.

Whitcomb, R.F., B.C. Whitcomb, and D. Bystrak. 1977b. Breeding bird census: mature tuliptree-oak forest. Am. Birds 31:91-92.

Whitcomb, R.F., B.L. Witcomb, and S.B. Whitcomb. 1975. Breeding bird census: upland mixed forest with small creek. Am. Birds 29:1089-1091.

Whitcomb, R.F., J.F. Lynch, P.A. Opler, and C.S. Robins. 1976. Island biogeography and conservation: strategy and limitations. Science 193:1030-1032.

Wilson, E.O., and E.O. Willis. 1976. Applied biogeography, pp. 522-524, in Cody, M.L., J.M. Diamond (eds.), Ecology and evolution of communities. Harvard Univ. Press, Cambridge, Massachusetts.

HABITAT SCARCITY, A BASIS FOR ASSIGNING UNIT VALUES FOR ASSESSMENT OF AQUATIC WILDLIFE HABITAT

James P. Fry
Missouri Department of Conservation
North Ten Mile Drive
Jefferson City, Missouri 65101

William L. Pflieger
Missouri Department of Conservation
Fish and Wildlife Research Center
1110 College Avenue
Columbia, Missouri 65201

Abstract: Current methods, for numerical evaluation of wildlife habitat, measure habitat suitability for selected species, weighted toward those important for uses such as hunting and fishing. Evaluation should address future optional needs as well as identified uses. Security of a species is inversely related to scarcity of its habitat, thus relative scarcity of a habitat type is a measure of the types important for future management options. A system for describing and assessing aquatic habitat in terms of relative scarcity and condition is being developed in Missouri. The fish fauna and a few physical factors will be used to delimit stream habitat types. Index values will be computed for each type based on its abundance and condition. Unit values of degraded habitat could be increased by habitat restoration as an exchange, for unit value losses caused by water resources projects, using habitat scarcity and condition as the primary basis for determining the location and amount of exchange.

The use of habitat quality rating scales and expression of value in terms of units has been met with mixed feelings among wildlife managers. Some are firmly opposed to "putting numbers on wildlife," an understandable opinion considering the way dollar values have been poorly used for this purpose. In our view, numerical ratings can be perfectly legitimate and highly desirable ways to reduce complex information into comprehensible form. Wildlife managers must recognize the importance of communicating appropriate forms of information to decisionmakers in other professions.

A number of methods have been proposed for numerical evaluation of wildlife habitat. These have been designed primarily to ascertain the amount of compensation needed to offset terrestrial habitat losses resulting from water development projects. The effectiveness of using numerical ratings for this purpose was recently demonstrated in Missouri. The State's view on construction of a large reservoir on an Ozark border stream was reversed when the so-called "Missouri System" (Daniel and Lamaire 1974) revealed that a substantial acreage of land would need to be purchased and upgraded for wildlife to compensate for project-caused terrestrial wildlife habitat losses. No system had been devised to display aquatic habitat value, but graphic illustrations were prepared to show the relative amount of aquatic habitat that has been degraded in the State's larger streams. Only 7 of the longest 25 streams in Missouri have not been impounded or partially channelized. Three of the seven have authorized reservoir projects. This and other experience caused us to consider the importance of numerically describing habitat scarcity for decisionmakers. Thus far, proposed habitat evaluation schemes have focused on habitat quality in terms of productivity with respect to individual or groups of species, often emphasizing huntable or catchable species. Relative scarcity of habitat type generally has not been directly considered or has only been viewed as important if a resident species is exceptionally rare.

All wildlife management agencies should consider two important responsibilities: 1) to manage wildlife resources for currently identified public needs (i.e., hunting, fishing, etc.), and 2) to maintain wild populations for future optional public needs.

Most current public needs for wildlife can be viewed in terms of resource supply and demand. Wildlife values for current uses can, in turn, be expressed monetarily using techniques such as those used by Horvath (1974) to measure consumers' views of recreational value. Unfortunately, very little effort has been expended to determine public expressions of dollar value for wildlife-oriented recreation.

The unknown or latent values inherent in all plant and animal species cannot be expressed directly in dollars. There are numerous examples of how obscure value may seem until a use is discovered and the value becomes evident. An often cited example points to our change in attitude toward the common green bread mold, Penicillium, after its antibiotic value became apparent. At one time people no doubt would have happily eliminated this organism from the face of the earth, an unthinkable view today, but not unlike attitudes still expressed toward some species. Our relative ignorance of latent values of plants and animals becomes more apparent with each new discovery. Also, the importance of securing the future of even the most obscure or seemingly "worthless" species becomes more apparent.

The security of each species hinges directly upon the security of its surroundings, including its entire sphere of other associated plants and animals. Such security is based largely on the amount of suitable habitat in existence. We can view wildlife habitat values as we view values of other natural resources. Minerals, for example, are valued and priced not only in terms of their utility and purity, but of their rarity. When depleted, or if rare to begin with, rarity is significant in determining their value.

We are attempting to develop a system for describing and developing a value scale for aquatic habitat in Missouri in terms of relative scarcity by type. A scarcity scale measurement could then be applied to a quantification of project-affected habitat to arrive at scarcity units. Such units could be used for comparing effects of various project alternatives on the future security of aquatic habitat management options. Additionally, scarcity units could be used as a basis for compensation measures to offset project damages to aquatic wildlife. Presumably, unit values of degraded aquatic habitat could be restored in exchange for project-related damage. Natural processes can accomplish restoration if these processes are allowed to occur. Public ownership and time may be all that is necessary for restoration, although construction could hasten replacement of value.

To apply this proposed system it is necessary to know the types of aquatic habitats in the state, the amount of each, and its condition with respect to man-caused disturbance. We are placing considerable emphasis on the development of a refined classification of stream habitats in Missouri.

We propose to use fish communities as indicators of different habitat types. We are taking this approach because we believe the species that comprise these communities can detect and respond to variations in important environmental parameters with a degree of precision that we could not hope to duplicate by attempting to quantify these parameters. Thus, a habitat classification based on the patterns of distribution and abundance of species should be a more refined classification than one based on the quantification of habitat characteristics.

We have elected to use fish rather than other elements of stream biota in developing our classification because fish collections provide the only readily quantifiable faunal data that are presently available statewide from Missouri streams. More than 1,400 fish collections, acquired over a period of approximately four decades, are available for analysis. We recognize the desirability of integrating other elements of the biota into our classification scheme, and to the extent that data on these groups are available it will be used to test and further refine the classification.

The utility of fish faunal data in delimiting broad aquatic habitat regions in Missouri was demonstrated previously (Pflieger 1971). From analyses of range limits and the species composition of collections, the state was divided into four principal regions: Ozark, Lowland, Prairie, and Big River. In studies now underway the same basic data used in recognizing these regions will be subjected to a more sophisticated analysis to provide a better definition of the regions and to recognize principal stream habitat types. The techniques to be used in this analysis will be those developed in recent yars for the use of computers in numerical classification. These include the computation of correlation coefficients, diversity indices, and factor analysis. After fish communities have been identified, all aquatic habitat in Missouri will be classified accordingly and quantified. A scarcity index value will be computed for each habitat type based on a straightforward analysis of the amount and condition of each type.

The system of stream habitat classification we are developing should have application nationally. The analytical procedures we are using could be applied to any area from which comparable fish distribution data are available. Also, since many of the principal elements in the Mississippi Valley fish fauna are found in Missouri, the stream habitat classification we develop should be generally applicable to most of the eastern United States.

We are measuring various kinds and degrees of aquatic habitat degradation in Missouri. Seriously degraded habitat will be omitted from the initial scarcity index computation, however the influence of various degrees of degradation on fish communities will be studied to determine possible refinements of the system. Habitat identified as degraded will be studied to evaluate its potential for restoration.

LITERATURE CITED

Daniel, Clarence and Robert Lamaire. 1974. Evaluating effects of water resource developments on wildlife habitat. Wildl. Soc. Bull. 2(3):114-118.

Horvath, J.C. 1974. Southeastern economic survey of wildlife recreation. Georgia State Univ., Environ. Res. Group.

Pflieger, W.L. 1971. A distributional study of Missouri fishes. Univ. Kansas Publ., Mus. Nat. Hist. 20(3):225-570.

THE EAST MOJAVE DESERT: AN EXAMPLE OF INVENTORY DESIGN AND HABITAT ANALYSIS

Kristin H. Berry
California Desert Plan Program
Bureau of Land Management
3610 Central Avenue, Suite 402
Riverside, California 92506

Abstract: Land use planning for wildlife on 16 million acres (6,477,733 ha) of national resource lands in the California Desert has required development of new and modification of old techniques for inventories and methods of faunal and habitat analysis. There is a growing need to address the requirements of all vertebrate species and habitat types, in addition to sensitive and significant species and areas. One approach is a detailed habitat classification system. Wildlife habitats were classified into discrete units according to ecological relationships between vertebrate species and their environments in a sample area of about 2 million acres (809,717 ha) in the East Mojave Desert. Two steps were used to select habitats: identification of key abiotic and biotic factors in the environment and identification of habitat preferences and limiting factors for each of 143 resident and breeding vertebrate species and for an additional 170 migrants. Key characteristics for biotic and physical factors in the environment and limiting factors for species included: soil and rock types, land forms, slope, elevation, composition and diversity of vegetation, vegetative cover, and proximity to water. This information was derived primarily from soils, land form, and vegetative data, which was mapped on aerial photographs at scales of 1:20,000 and 1:62,500. There were 43 major soil and land form mapping units and over 800 vegetative transects, each of which was associated with polygons or map units. From these map units and species preference data, 33 wildlife habitats were selected, described, and mapped. The wildlife habitat types were used as a basis for choosing sites for field surveys (small mammal trapping, winter and breeding bird surveys, transects for reptiles, etc.). Results of field inventories are presented, and the use of this habitat classification system for analyzing faunas and predicting the distribution and relative abundance of species is discussed. The habitat classification system also can be utilized for study of individual species, groups of species, and unique areas.

INTRODUCTION

The California Desert, as defined here, covers approximately 20 million acres (8,097,166 ha) and extends from southern Mono County in the north to the border of Baja California, Mexico in the south and from the eastern slopes of the Sierra Nevada, Inyo, White, Tehachapi, San Bernardino, San Jacinto, and Santa Rosa Mountains in the west to the borders of Nevada and Arizona in the east. The Colorado River and its western edges are excluded from the California Desert as defined here (Figure 1). Over 60 percent of this area is under the jurisdiction of the U.S. Department of Interior, Bureau of Land Management (BLM). Other major land management agencies include the Department of Defense, National Park Service, and the California State Parks and Recreation Department. The major private landowner is Southern Pacific Railroad Company.

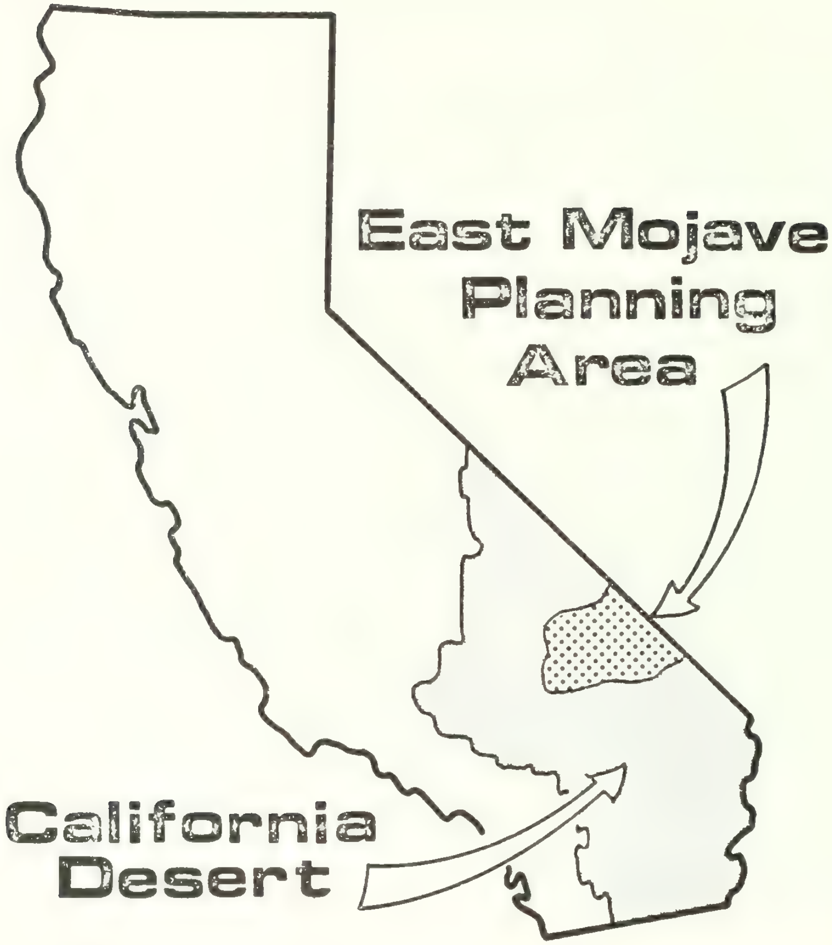


Figure 1. The East Mojave planning area, an approximately two million acre (809,717 ha) area in the California Desert.

In 1972 the BLM established a special task force to prepare intensive inventories and land use plans for the California Desert. The task force, called the California Desert Plan Program, was created to address problems of growing demands on resources and of environmental degradation. Since 1960, public needs for energy sites, geothermal development, transmission line corridors, livestock grazing, recreation use, and mining and mineral development had escalated to the point where intensive land use planning was necessary to protect and manage fragile cultural, biological, and historical resources, and important energy sources.

The BLM approached the problems of long range planning and multiple resource use by assembling a staff of resource professionals in the fields of soil science, botany, range science, recreation, wildlife biology, geology, minerals and energy, archaeology and cultural resources, and land use planning. The California Desert was divided into 27 areas or planning units of one-half million to 2 million acres (202,429 to 809,717 ha), each of which would receive intensive surveys and analysis. Land use plans were to be prepared for each region based on existing and new data, current public needs, and long range projections for future land use requirements. Speed was essential; irreplaceable resources were deteriorating or being destroyed as visitor use and energy demands increased. Each region would be surveyed and analyzed and land use plans prepared in an average of 9 to 12 months.

The intensive studies began in 1973; since that time six planning areas have been completed and a seventh is underway. This paper will present the methods used to analyze and display data for the wildlife resource in one planning area, the East Mojave (Figure 2). Criteria for a system of data acquisition, evaluation, and habitat classification were established and a habitat classification system developed. The classification system is based on the ecological relationships of vertebrate species with the abiotic and biotic environment. Inventories were designed using the habitat classification system as a base. Some of the results of the inventories are presented here.

CRITERIA FOR ACQUISITION, ANALYSIS, AND DISPLAY OF WILDLIFE DATA

Questions were raised about how to efficiently handle data acquisition, analysis, and display for all resources. The wildlife data presented complex problems because of the large number of species and habitats. The East Mojave area was a challenge; it is a diverse area where three major desert systems, the Great Basin, Mojave, and Colorado or Sonoran Deserts, join. In addition, there are also enclaves of small communities typical of coastal Southern California chaparral and the Rocky Mountains. The diverse habitats support about 300 species of vertebrates. Data were needed on distribution, habitat preferences, life histories, and ecological relationships for all 300 species.

Any system for analyzing and displaying data had to meet several criteria. The system must:

1) be usable to wildlife biologists with a variety of backgrounds and often limited knowledge of the habitats and species occurring in the desert and must be easily understood by resource specialists and managers who are non-biologists. (There is a high turnover of personnel in the BLM; biologists stay in assignments an average of 2 years.)

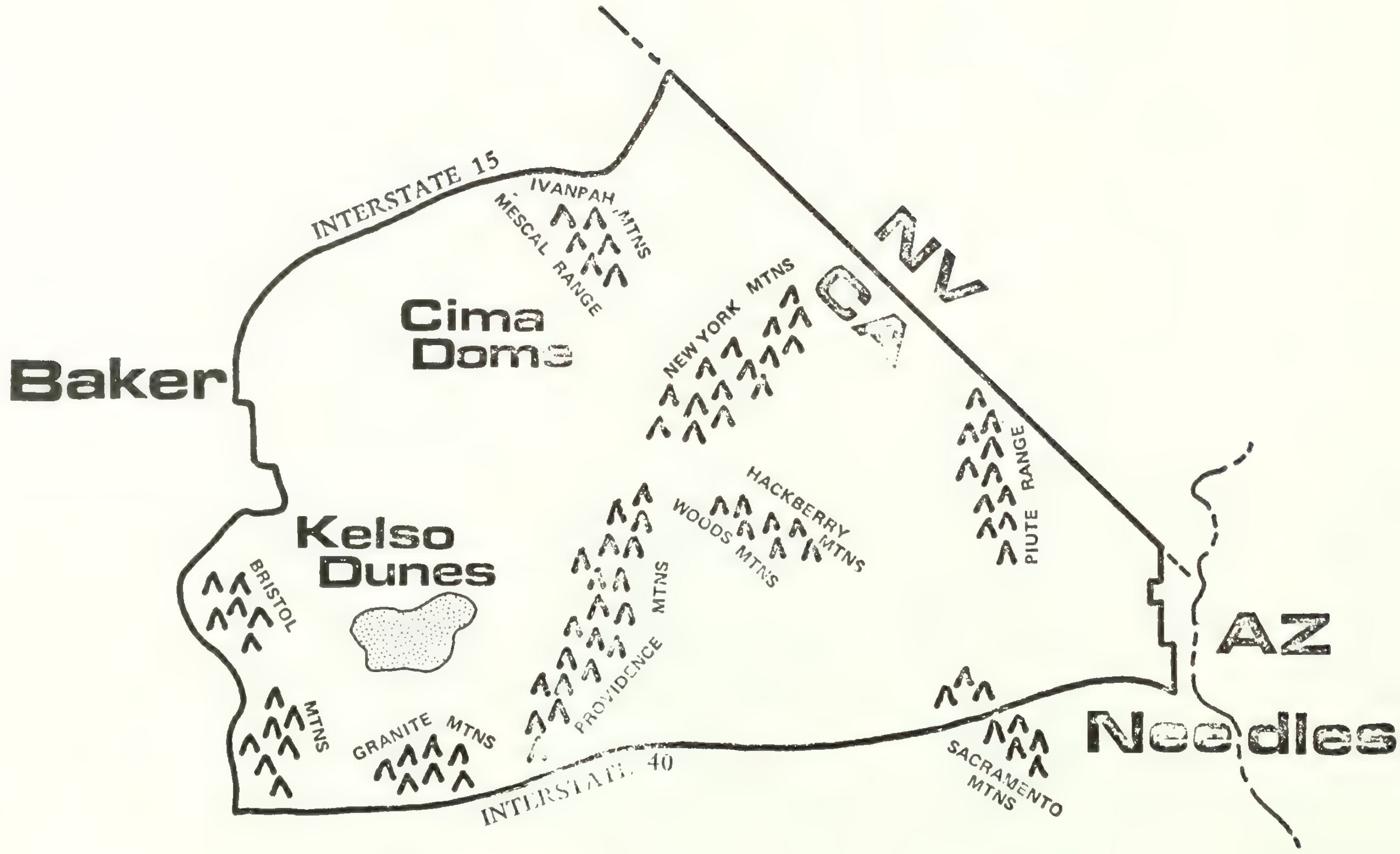


Figure 2. Major geographic features in the East Mojave area.

2) provide an easily updated and permanent data bank for present and future management needs.

3) address the BLM's directives for the wildlife program. For example, the Bureau manages wildlife habitat, not species. Two of its major objectives are to stabilize habitats in declining condition and to maintain or improve habitats in satisfactory condition. Data collection techniques and analysis must address the principal factors or uses that influence habitat condition, either positively or negatively. In the California Desert, off-road vehicle use, livestock grazing, expanding feral burro populations, mining, power plant siting, geothermal development, and harvest of vegetation all have an impact on wildlife habitat.

4) allow for special attention and consideration for certain species (endangered, threatened, rare, BLM "sensitive" species, etc.), while at the same time providing for management of all vertebrates and important invertebrates.

5) provide a means for predicting distribution of vertebrates in areas where there is no data.

6) identify species and areas for which data are available or not available; clarify the type of information available.

THE APPROACH

The criteria were met by using a twofold approach: by study of individual vertebrates and by a classification system for habitat type.

SPECIES

At the beginning of the study in 1975, the East Mojave planning area was estimated to have about 300 vertebrate species. Of these, 78 needed special attention for management purposes (56 breeding species, 22 migrants). These species were considered important for one or more of the following reasons. They:

1) are listed on the Federal endangered or threatened species lists;

2) are listed on California endangered, threatened, or rare species lists;

3) are fully or partially protected by California laws;

4) are under consideration for the BLM's "sensitive" species list;

5) are listed on the Audubon Society's Blue List of Birds;

6) have limited habitat preferences and/or geographic distribution;

7) are limited in numbers due to position in food chain;

8) possess consumptive or non-consumptive recreational values;

9) have commercial value; and

10) have scientific and/or educational values.

All species in this group were termed "significant species." Basic information about each species was needed on density, distribution, and status in the East Mojave area and elsewhere in the geographic range, about habitat preferences, and about land uses that were having or could have an effect on habitat and populations.

WILDLIFE HABITAT TYPES

The second part of the approach was to study all species within the habitat they occupied. Wildlife habitats can be described in terms of physical and biological aspects of the environment. Vertebrates generally occur in natural groups based on their preferences for such factors as soil texture and surface characteristics, land form, percent cover of vegetation, floral composition, structure of vegetation, degree of slope, elevation, proximity to water and the presence or absence of other vertebrate species.

In the past, descriptions of wildlife habitats have closely followed descriptions of vegetative and floral communities (Johnson, et al., 1948; James and Shugart, 1970; Munz, 1974; Thomas, et al., 1976; Cheatham and Haller in press). The team of resource specialists on the Desert Plan Staff included experts in zoology, soil science, geology, botany, and range science, and they developed a multidisciplinary method of describing and analyzing wildlife habitat types. The extensive and intensive data collected on soils, water resources, land forms, and vegetation were integrated into wildlife habitats.

DELINEATION OF WILDLIFE HABITATS

STEP 1

During the first step, data were collected on soil series and land forms, and on vegetation, by interpretation of aerial photographs and extensive ground truthing.

Soils and Land Forms

Studies on soils and land forms were undertaken using two scales of imagery: low-altitude color photographs at a scale of 1:20,000 and high flight U-2 photographs at a scale of 1:130,000. Photo interpretation of the low-altitude color photographs was almost 80 percent completed when it was abandoned for the smaller scale U-2 images. The low-altitude color photographs presented three major problems: color and tone variations between and within flight lines gave false indications of changes in soil character; there was considerable variation of scale in topography, making matching between photographs difficult; and the large scale images covered such a small area that choice of representative sample sites for soil pits was difficult. There were often duplications and omissions in choosing the sample pit sites. In contrast, the black and white U-2 photographs maintained color control, had minimal scale variations, and allowed rapid identification of potential soil associations and accurate selection of sample sites. The U-2 images had high resolution and were easily enlarged to a scale of 1:62,500 without loss of detail (Hansen et al., 1976).

The photographs were used for delineation of potential soil associations, which were validated by field surveys. Field techniques included: transects; soil pits, augering, and examination of exposed sections in road cuts, mineral claim pits, and stream valley walls; and visual inspection of landscape features (Hansen et al., 1976).

Using a land form system, soils were classified into nine categories: playas, major stream courses, plains, terraces, sand sheets, sand dunes, mesas, hills, and mountains. There were 21 major soil associations and these, combined with land forms, produced 43 mapping units (Appendix A) (Hansen et al., 1976).

Polygons of soil associations and land forms were transferred from the U-2 images to U.S. Geological Survey 15 minute series topographic maps (Figure 3).

Vegetation

The two types of remote images (low altitude color and black and white U-2 photographs) were also used to study vegetation and to establish preliminary and final subdivisions of vegetational cover and composition. Units of cover or stands of vegetation were outlined as polygons directly on the black and white small scale U-2 photographs; the larger scale color photographs were used for clarification of detail.

The pretyped photographs then were taken to the field for verification of boundary lines and analysis of vegetation in each polygon. All polygons were checked for floristic and structural homogeneity on the basis of visual appearance, and boundary lines were shifted to match visual observations. One or more representative areas in each polygon were selected for 100 pace toe-point transects (Johnson, 1976).

Over 800 transects were made in the polygons. Data were collected on elevation, slope direction, percent slope, land forms, surface characteristics of soil (litter, rock size), basal area and canopy cover of perennial plants, and presence of annuals (species list). In order to estimate composition of perennial plants, the occurrence of the nearest perennial species within a 180° arc of the toe point was noted. Thus 100 plant occurrences were recorded by species for each transect. The composition derived by this method was termed "nearest point to plant composition" (NPPC). The NPPC is not the same as a cover composition based on actual percent of species cover. Color pictures also were taken in the vicinity of each transect. Finally, polygons were transferred from the aerial photographs to U.S. Geological Survey 15 minute series topographic maps (Figure 4) (Johnson, 1976).

STEP II

The 1 species of fish, 1 amphibian, 36 reptiles, 205 birds, and 48 mammals in the East Mojave area occur in natural groups because of preferences or requirements for certain features or groups of features in the environment. Some species have very specific habitat requirements and will occur only in a few areas, whereas others are wide ranging and tolerate a variety of conditions. Knowledge of these preferences aided in defining faunal groups. There are numerous preferences and relationships; only a few examples are given here.

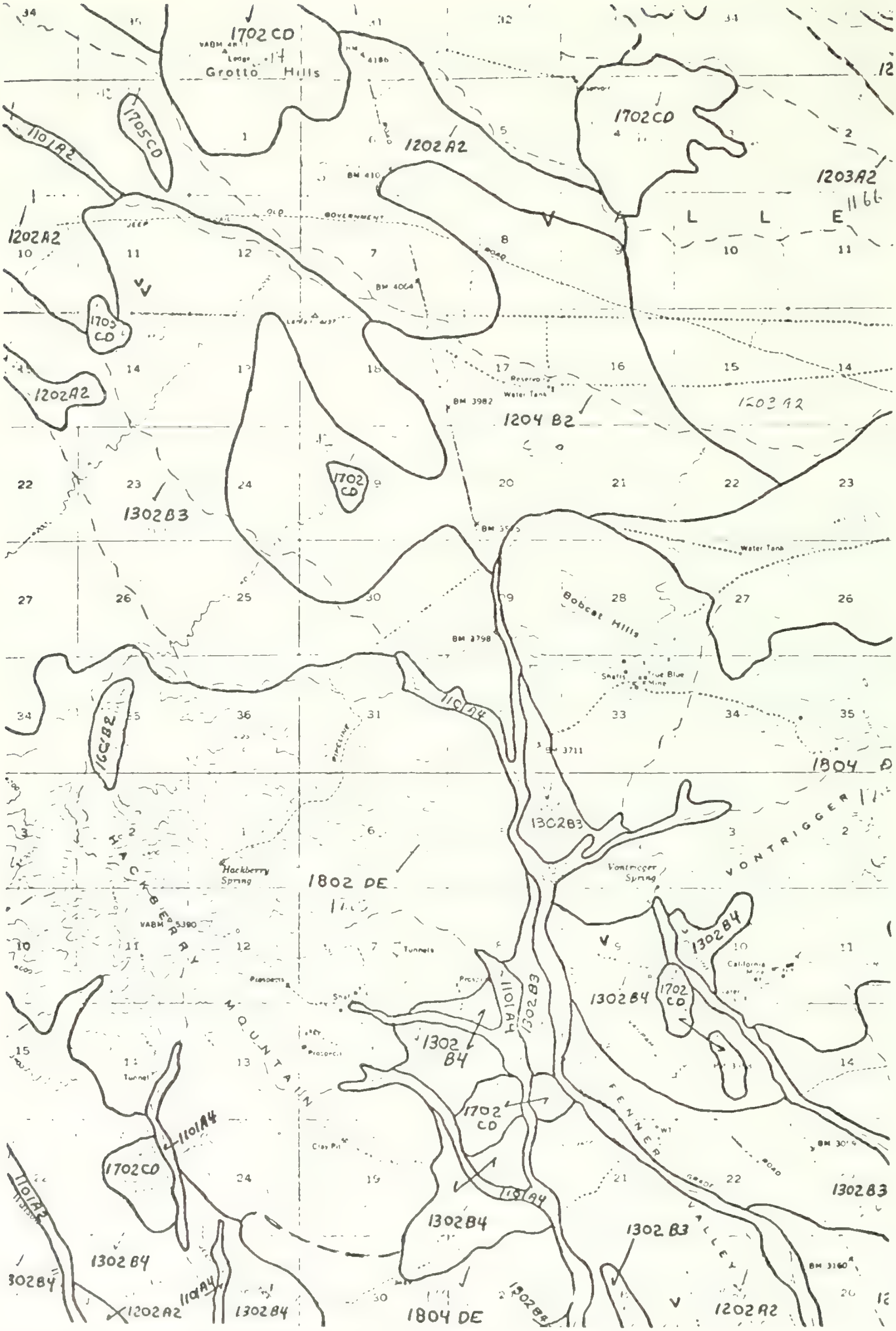


Figure 3. Typelines of soils and landforms outlined on a U.S. Geological Survey (15 minute series) topographic map in southern Lanfair Valley, East Mojave area. See Appendix I for legend.

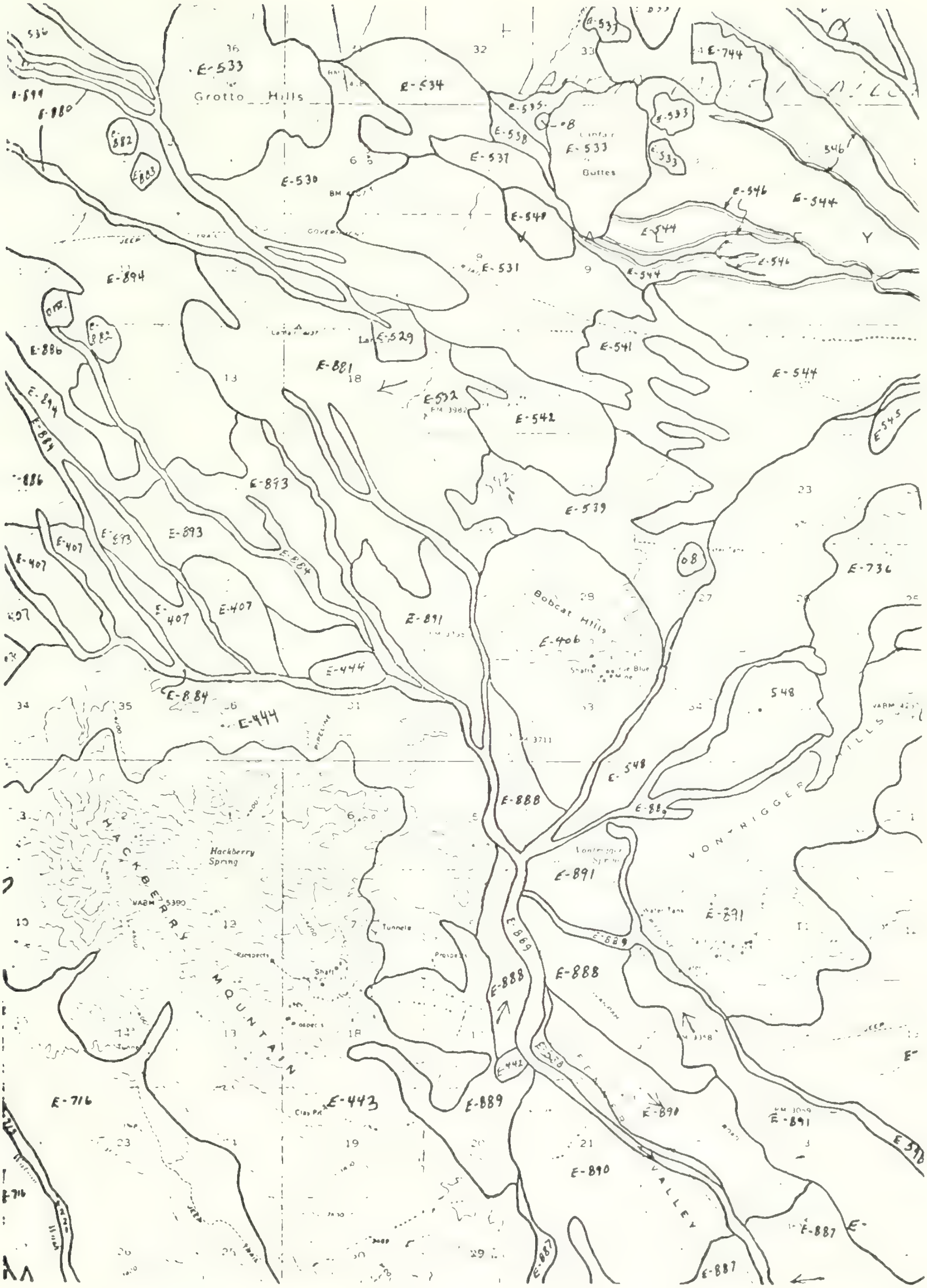


Figure 4. Typelines for vegetative polygons outlined on a U.S. Geological Survey (15 minute series) topographic map in southern Lanfair Valley, East Mojave area. Each number (E-443, E-716) refers to a transect sheet with attached photograph.

1) Some species of vertebrates occur only in areas with certain soil textures. Prime examples are species limited to windblown or eolian sands: Mojave fringe-toed sand lizard (Uma scoparia), desert kangaroo rat (Dipodomys deserti), and 9 species of insects including the giant sand treader (Ammopelmatus kelsoensis). Others favor the eolian sands, but can be found elsewhere (desert iguana, Dipsosaurus dorsalis; shovel-nosed snake, Chionactis occipitalis).

2) Soil surface characteristics, such as presence, size and spacing of rocks, are critical to such species as the canyon mouse (Peromyscus crinitus) and chuckwalla (Sauromalus obesus).

3) Certain species show preferences for habitats with joshua trees: desert night lizard (Xantusia vigilis), ladder-backed woodpecker (Dendrocopos scalaris), ash-throated flycatcher (Myiarchus cinerascens).

4) Dense stands of catclaw (Acacia greggii) occur in some washes and are parasitized by mistletoe (Phorodendron sp.). They attract phainopeplas (Phainopepla nitens), who are frugivorous and feed on mistletoe berries.

5) Dense stands of staghorn cholla and/or darning needle cactus (Opuntia acanthocarpa, O. ramosissima) are believed to be a prerequisite for nesting by the Bendire's thrasher (Toxostoma bendirei).

STEP III

The initial step of integrating data from studies of soils, land forms, and vegetation was accomplished by grouping the 43 soil and land form mapping units and more than 800 vegetative polygons and transects into categories of significance to the vertebrate species. Soils and land forms were placed into 11 categories:

1) scarp front and/or rough, broken land;

2) ephemeral stream with gravelly or stony coarse sands, 0-3 percent slope;

3) gravelly loamy sands, gravelly sandy loams, and gravelly very fine sands, 0-8 percent slopes;

4) cobbly loamy sand and cobbly loam; 0-8 percent slope;

5) stony loamy sand, stony fine sandy loam, and stony silt loam, 0-8 percent slope;

6) loamy fine sand (eolian), 0-8 percent slope;

7) fine sand dunes, 31-60 percent slopes;

8) Pleistocene and recent lava flows;

9) playas;

10) moderately deep gravelly sandy loam, 9-60 percent slopes; and

11) shallow, gravelly loamy sand, 31-60+ percent slopes.

The vegetative transects were sorted according to vegetative aspect [(tallest, most obvious perennial in each transect/polygon, e.g., smoke tree (*Dalea spinosa*), joshua tree (*Yucca brevifolia*), pinyon pine (*Pinus monophylla*)]; number and kinds of canopy layers; presence of certain taxa; diversity; and percent cover. Other factors considered were: general topography; presence, size, and clustering of rocks; litter; and elevation. Pictures attached to the transect forms aided immensely in determining presence and size of rocks and general topography.

Initially the transects were placed into about 70 groups with broad categories in saltbush (*Atriplex* sp.), creosote bush scrub (*Larrea tridentata*), Mojave yucca (*Yucca schidigera*), Joshua Tree Woodland Sagebrush (*Artemisia tridentata*), pinyon-juniper woodland, and wash communities. These communities are reminiscent of the plant communities described by Munz (1974) and Thorne (1976a, b). The 70 groups were gradually grouped into 33 wildlife habitat types, using information on preferences of the vertebrates.

STEP IV

The 11 mapping units for soils and land forms were outlined on one set of 15 minute series topographic maps and the 33 units for vegetative communities on another. Using a light table, the vegetative maps were placed on top of the soil and land form maps. The 44 separate units were matched and blended into 33 wildlife habitat types. After type lines were drawn and redrawn, the habitats and boundaries were checked in the field for accuracy and modified where necessary.

The 33 habitat types chosen for the East Mojave were:

Playas
Saltbush
Dunes
Creosote-Windblown Sand
Creosote-Burrobush
Creosote-Mixed Shrub
Rocky Slopes-Creosote
Teddy Bear Cholla-Creosote
Ocotillo-Creosote
Mojave Yucca-Creosote
Mojave Yucca-Cholla
Joshua Tree-Creosote
Joshua Tree-Mixed Shrub
Joshua Tree-Blackbrush
Grassland
Rocky Slopes-Yucca
Blackbrush
Sagebrush
Cheesebush Washes
Acacia Washes--Low Elev.-Low Density
Acacia Washes--Low Elev.-High Density
Acacia Washes--High Elev.-Low Density
Acacia Washes--High Elev.-High Density
Smoketree-Acacia Washes
Desert Willow Washes
Upper Elevation Brushy Washes
Riparian
Foothill Ecotones
Sagebrush-Juniper
Oak-Pinyon-Juniper
Pinyon-Juniper
Pinyon
White-Fir-Pinyon

All habitat types could be easily distinguished visually. One type which might puzzle the reader is Foothill Ecotones, a combination of several small habitats at areas of about 4,000 to 5,000 ft (1,219 to 1,524 m) elevation where junipers and pinyons intergrade with three species of yuccas--joshua tree, Mojave yucca, and Spanish dagger (*Yucca baccata*). Six distinct vegetative types could be identified visually and through transects. All had pinyon and juniper mixed with: Mojave yucca; Mojave yucca and staghorn cholla;

Spanish bayonet; Spanish bayonet and staghorn cholla; joshua tree; or joshua tree and staghorn cholla. All six types had readily distinguishable faunas. However, we noted during field validation that the vegetative polygons did not clearly delineate differences and there were too few transects to draw accurate boundaries. Therefore the six pinyon-juniper-yucca types were grouped into one type, Foothill Ecotones (Figure 5).

Two of the wildlife habitats are described as examples of an integrated habitat analysis.

Creosote-Windblown Sand

Location. Two areas: northeast shore of Ivanpah Dry Lake at elevations of 2,600 to 2,820 ft (792 to 859 m), and the Kelso Dunes-Devil's Playground area from the vicinity of Cowhole Mountain south and east to the Kelbaker Road at elevations of 1,200 to 2,400 ft (366 to 731 m).

Vegetation and Soils. Five 100 pace toe-point transects were taken. Cover of perennial vegetation averaged 5.4 percent (range 1-11) with galleta grass (*Hilaria rigida*) composing an average of 54.6 percent, burrobush (*Amborisa dumosa*) 24.75 percent, creosote bush 22.6 percent, and Indian rice grass (*Oryzopsis hymenoides*) 3.67 percent. Other plant species present in lesser amounts or as a trace included panicum (*Panicum urvilleanum*), goldenhead (*Acamptopappus sphaerocephalus*), cheesebush (*Hymenoclea salsola*), and darning needle cholla.

There are two major soil types: fine loamy eolian sand, and dunes of fine sand with steep slopes. Loamy sand and ephemeral stream courses are represented to a minor degree (Hansen et al., 1976).

Vertebrate Species. There are a total of 43 vertebrate species here: 19 reptiles, 7 birds, and 17 mammals. Eighteen are considered significant: 7 reptiles, 4 birds, and 7 mammals. The Mojave fringe-toed lizard is the most conspicuous species and reaches its highest population levels here. Burros of the desert and Merriam kangaroo rats are conspicuous. The desert iguana is also common and the long-tailed brush lizard can be found in branches of creosote bushes. The habitat is used for foraging by the prairie falcon, and LeConte's thrasher occasionally breeds in the large shrubs. Feral burros eat the grasses. (See Table 1 for an example of data display for the vertebrates.)

Creosote-Mixed Shrub

Location. Generally at elevations of 1,500 to 3,500 ft (457 to 1,067 m), range 1,400-3,800 (427 to 1,158m) above Creosote-Burrobush and below Mojave Yucca-Creosote and Mojave Yucca-Mixed Shrub Habitat types. Localities are widely scattered. The large expanses are confined primarily to the western, southern, and eastern parts of the area, in particular Kelso Wash, southwest and east of the Kelso Dunes, slopes of the Bristol Mountains, Granite Pass, east base of the Providence Mountains to north of Van Winkle Spring, eastern Clipper Valley, east and west of Blind and Halfway Hills, southwest of Vontrigger Hills, Piute Valley, east of Dead Mountains, and north of Homer.

Vegetation and Soils. Seventy-one 100 pace toe-point transects were made, revealing 73 perennial species. Vegetative cover averaged 10 percent (range 2-31) with creosote bush and burrobush each composing an average of 32 percent of the cover. Other common species were 4.5 percent goldenhead,

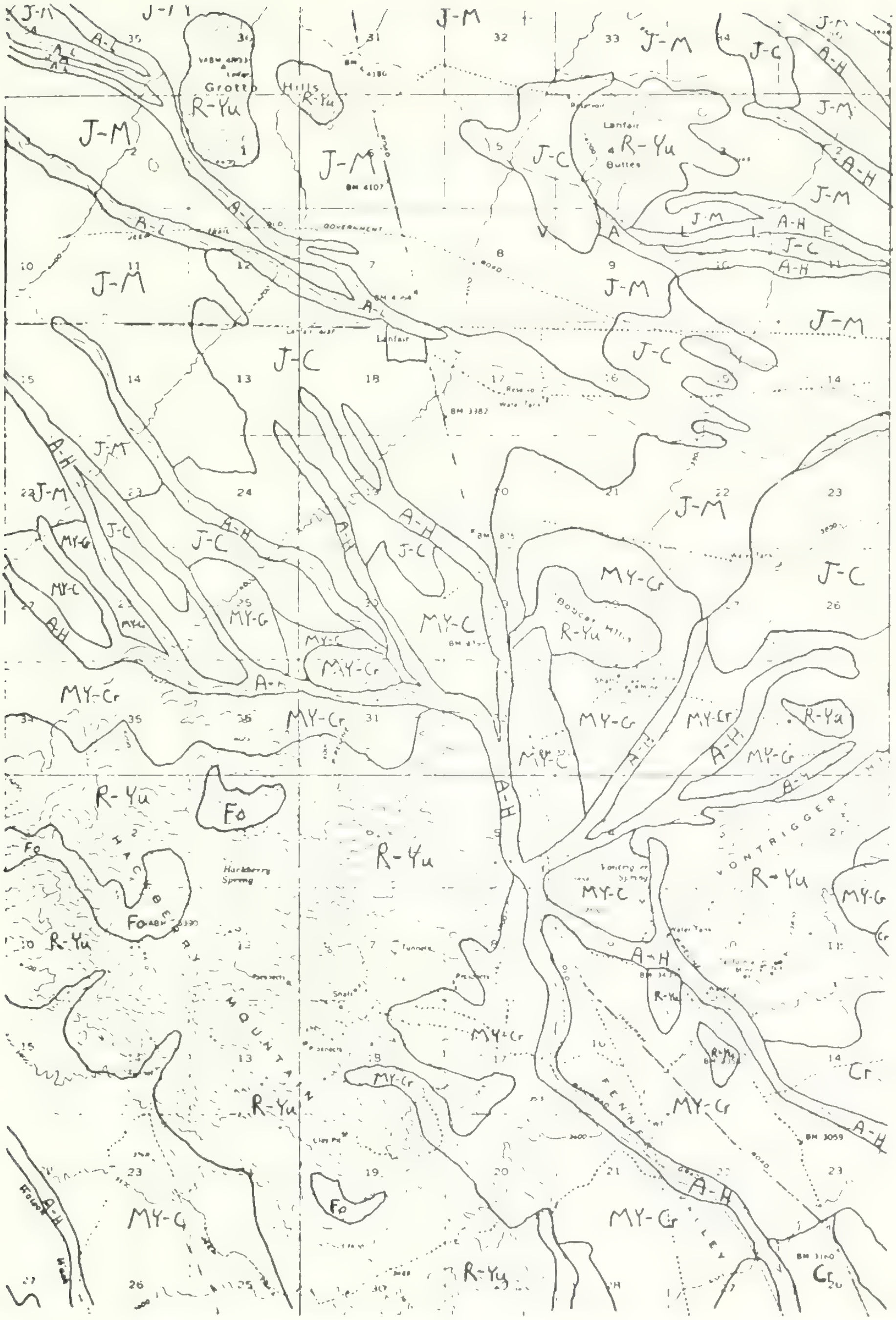


Figure 5. Typelines for wildlife habitats, drawn using data from Figures 4 and 5, and further field observations. Legend for wildlife habitats: Cr = Creosote-Burrobush; R-Yu = Rock Slopes-Yucca; MY-Cr = Mojave Yucca - Creosote; MY-C = Mojave Yucca-Cholla; J-C = Joshua Tree-Creosote; J-M = Joshua Tree-Mixed Shrub; A-L = Acacia Wash-Low Elevation-High Density; A-H = Acacia Wash-High Elevation-High Density.

Table 1. Vertebrates Occurring in Creosote-Windblown Sand in the East Mojave Planning Area (Examples Only)

Species	Significance	Status (As Resident)	Abundance	Presence	
				Probable	Verified
Desert tortoise (*Gopherus agassizi*)	X	Permanent	Uncommon		X
Desert banded gecko (*Coleonyx v. variegatus*)	X	Permanent	Uncommon		X
Desert iguana	X	Permanent	Uncommon		X
Zebra-tailed lizard (*callisaurus draconoides*)		Permanent	Common		X
Mojave fringe-toed lizard	X	Permanent	Abundant		X
Turkey vulture (*Cathartes aura*)		Summer	Rare		X
Red-tailed hawk (*Buteo jamaicensis*)		Permanent	Rare		X
Prairie falcon (*Falco mexicanus*)	X	Permanent	Rare		X
Horned lark (*Eremophila alpestris*)		Permanent	Uncommon		X
Little pocket mouse (*Perognathus longimembris*)		Permanent	Common		X
Merriam's kangaroo rat (*Dipodomys merriami*)		Permanent	Fairly common		X
Desert kangaroo rat		Permanent	Fairly common		X

3.6 percent Anderson thornbush (Lycium andersoni), 2.2 percent Nevada joint fir (Ephedra nevadensis) and trace amounts of California buckwheat (Eriogonum fasiculatum), darning needle cholla, staghorn cholla, and beaver-tail cactus (Opuntia basilaris).

The major soil types are gravelly and cobbly loamy sands. Several other types are present and include gravelly sandy loams, cobbly or stony fine sandy loams, fine loamy eolian sand, ephemeral stream courses, stony silt loam, cobbly loam, very steep slopes, and rough, broken land.

Vertebrate Species. Creosote-Mixed Shrub supports 63 species, including 22 reptiles, 16 birds, and 25 mammals. Twenty-two are significant species (6 reptiles, 7 birds, and 9 mammals), etc.

THE USE OF WILDLIFE HABITAT CLASSIFICATION SYSTEMS IN DESIGNING INVENTORIES

After wildlife habitat types are identified, existing data in the form of museum and literature records can be related to the habitat types and analyzed. Gaps in information can be identified for each habitat type. Then field surveys can be designed efficiently to focus on habitats or species where there is little or no data.

ACQUISITION OF EXISTING DATA

A considerable amount of data can be found in the literature and in museums in the form of specimens. In the East Mojave area a major study was undertaken between 1917 and 1945 by the Museum of Vertebrate Zoology, University of California, Berkeley (Johnson et al., 1948). These field studies were confined primarily to three of the nine major mountain ranges. Specimens from this and other collections (many of which are uncited in the literature) are housed in such institutions as the Los Angeles County Museum of Natural History, San Diego Natural History Museum, California Academy of Sciences, Western Foundation of Vertebrate Zoology, and San Bernardino County Museum. Prior to the initiation of the BLM study in 1975, there were data from 137 localities for reptiles (304 citations), 123 for birds (511 citations), and 135 for mammals (292 citations). Many of these locality records were for only one specimen. There were only 16 localities with three species or more cited for reptiles, 37 for birds, and 102 for mammals (most of which were for rabbits and ground squirrels).

Additional data were available in the form of comprehensive field notes from two scientists; one had banded numerous bats in caves and mine tunnels and the other had made notes on amphibians and reptiles over a period of 10 years for a research project (P. Brown, University of California at Los Angeles; T.W. Brown, California State Polytechnic University, Pomona, respectively).

An analysis of the museum records, literature citations, and field notes for the East Mojave prior to 1975 revealed that the collections and observations had been limited primarily to a few major mountain ranges and to the dense joshua tree woodland of Cima Dome (Figures 2, 3, and 6). Data were lacking entirely for the majority of the habitats, e.g., Dunes, Smoketree-Acacia Washes, four Acadia Wash types, High Elevation Brushy Washes, Oak-Pinyon-Juniper, Grassland, and Ocotillo-Creosote.

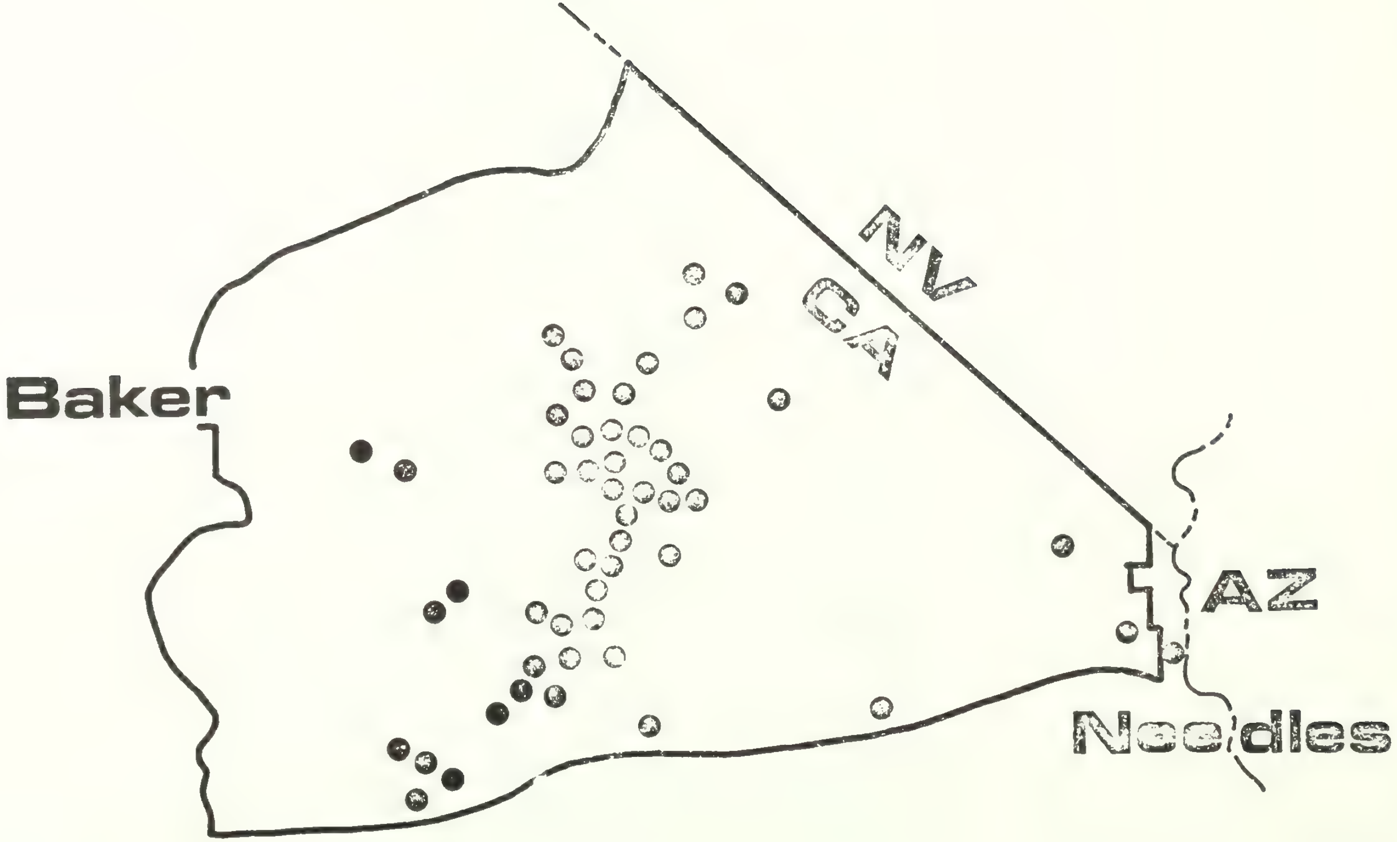


Figure 6. Available museum and literature records for mammals for the East Mojave area prior to 1975. Note the clumped distribution of localities and the relationship to some major mountains shown in Figure 2.

PROBLEMS WITH LOCALITY RECORDS IN ANALYSES OF VERTEBRATE DISTRIBUTIONS

A major problem surfaced when trying to relate literature citations and locality data from museum specimens to specific habitat types. Many observations in the literature and museum specimens referenced general localities such as: Kelso, San Bernardino Co.; Valley Wells, San Bernardino Co.; Indian Springs, San Bernardino Co.; or 20 mi (32.2 km) N. Kelso, San Bernardino Co. These kinds of records are not useful to studies of distribution and habitat, because in most cases the specimen cannot be associated accurately with a particular habitat type. Observations or collections could have been made within 1 or 2 miles (1.6 to 3.2 km) of the site, have been taken on a highway nearby, or in some instances be at one of two or three springs with the same name. We have checked some citations with the original collectors and have found discrepancies between the actual collection point and the recorded point.

Citations that were most useful had localities recorded as follows: 20 mi. N, 6 mi. E Kelso, 3,500 ft, San Bernardino Co.; or SW1/4 Sec. 36, T. 10 N, R. 3 E, Homer Mtn., 3,800 ft, San Bernardino County, California. Specimens collected there could be associated easily with a habitat type. Field observers and collectors should be encouraged to write more detailed locality descriptions, so that future investigators can find the exact location of the observation or collection, then the data can be related to soil type, topography, slope, vegetation, etc.

USE OF HABITAT TYPES TO MAKE PREDICTIONS

We made the assumption that data collected in one site in a particular habitat could be used to predict the occurrence of species elsewhere in the same type. Predictions are likely to be more accurate the nearer the collection site lies to the area in question. Predictions also increase in accuracy as data on vertebrates accumulates.

INVENTORIES

Field surveys were designed to fill data gaps both on significant species and on general surveys for each habitat type. Emphasis was placed on sensitive and/or limited habitats, significant species, and on habitats that were widespread, but for which there was little information.

Twenty-one man months were spent in field inventories for amphibians, reptiles, birds, and mammals between 1975 and 1976. Amphibians were sought at springs and seeps and in moist woodlands. Lizards and tortoises were censused using transects; snakes were sought by driving on paved roads at night. Specimens were collected for some species of reptiles by hand, noose, or gun. Surveys for birds were made using several techniques. Breeding and winter bird surveys were accomplished for three and six habitat types, respectively (Remsen, et al., 1976a, b, c, d, e, f; Remsen 1977, Kubik and Remsen, 1977a, b). Mist nets were set for birds in selected areas and some specimens were taken. Small mammals were trapped with Sherman live traps and Victor and museum special snap traps (31,725 trap nights). Bats were banded, and some collected, using mist nets. Special studies were undertaken on significant species such as Bendire's thrasher and the desert tortoise (Berry et al., 1976).

In all cases, data on locality were recorded, for each observation of a vertebrate species, by: township, range, quarter section, elevation, habitat type, and condition. Notes were made concerning numbers, sex, age class, and behavior.

SOME RESULTS OF INVENTORIES AND HABITAT ANALYSIS

The systematic approach to inventories produced results exciting to the scientist and of use to managers who make land use decisions. For example, there were discoveries of isolated and/or relict populations of a few species, range extensions for several species, and new data on distribution and habitat preferences for most species.

The information was displayed by habitat and by species. For each habitat type, information was available on acreage in the East Mojave area, verified or probable presence of vertebrate species, estimated or relative abundance for each species, status (permanent or summer resident, winter visitant, migrant, etc.), and significance (endangered, rare, fully protected, etc.) (Table 1). In some cases detailed information was gathered on abundance and status, e.g., in breeding and winter bird surveys (Tables 2 and 3). The three breeding and six winter bird surveys revealed large differences in magnitude in density and diversity among habitat types. Note that the Acadia Wash and Riparian habitat types far exceeded the other habitat types in density of bird populations. The results of the nine census studies indicated that desert washes, such as the Acadia Wash, can be highly sensitive and valuable sites for birds, though not offering the density and diversity found in riparian situations.

With this census information, the 33 habitat types could be evaluated according to amount of acreage, number of species, and the numbers and kinds of significant species (Table 4). For example, among the six habitats shown, the Creosote-Windblown Sand habitat supports the lowest number of vertebrate species and "significant" species. The Creosote-Windblown Sand habitat may, at first glance, appear to have less value than other habitats; however, it possesses nine endemic species of insects being considered for endangered status by the Office of Endangered Species. Two types--Riparian and Oak-Pinyon-Juniper--have special values; they are very limited in acreage not only in the East Mojave but in California and the entire West. The particular kind of Oak-Pinyon-Juniper found here is not known to occur elsewhere. Both Riparian and Oak-Pinyon-Juniper habitats support diverse populations of vertebrates and large numbers of significant species (Berry et al., 1976).

In addition to the analysis of species by habitat type, information on each vertebrate species also was summarized in species accounts. Each species account included such topics as: distribution locally as compared to elsewhere in the geographic range, locality records (literature and museum citations and sight records), habitat preferences, seasonal occurrence and abundance, and condition of populations and habitat. The emphasis in species accounts was on the significant species (Berry et al., 1976).

Table 2. Breeding Bird Census Studies in the East Mojave Planning Area

Habitat	Density (no./100 acre)	No. species
Creosote-burrobush	2	2
Acacia wash-low elevation-high density	110	12
Riparian	863	13

Table 3. Winter Bird Census Studies in the East Mojave Planning Area

Habitat	Density (no./100 acre)	No. species
Creosote-burrobush	3	2
Creosote-mojave yucca	4	3
Joshua tree-mixed shrub	36	6
Pinyon-juniper	52	12
Acacia wash-low elevation-high density	187	17
Riparian	315	26

Table 4. Vertebrate Species Occurring in Six Habitat Types in the East Mojave Area

Habitat type	Total species	Number of significant species	Habitat acreage (ha)
Creosote-windblown sand	44	18	2,547 (1,031)
Joshua tree-mixed shrub	95	37	8,571 (3,470)
Foothill ecotones	99	38	4,670 (1,891)
Oak-pinyon-juniper	112	37	55 (22)
Riparian	118	35	6 (2.4)
Acacia wash-low elevation-high density	78	26	250 (101)

USING SPECIES AND HABITAT DATA AS A PREDICTIVE TOOL

One criterion for this habitat classification system was to provide a data base for making predictions about distribution of vertebrates in areas lacking data. The biologist and manager need to be able to point to a site on the map and after the habitat type is identified, draw up a list of possible species occurring there, whether or not there have been biological surveys in the immediate vicinity.

Predictions can be made now with the data available for the East Mojave. A site on the wildlife habitat map can be selected (e.g., Figure 5), and a table showing the occurrence, abundance, and significance of the vertebrate species (e.g., Table 1) examined. Further information on collecting localities and species' preferences is available in species accounts and on maps showing museum collecting sites and observations recorded in the literature.

Depending on the quality of the data and proximity to the site in question, the scientist can draw inferences on distributions and abundance of vertebrates in a particular area. Accuracy is likely to increase as data accumulates. Even with the relatively meager data available now on many species of reptiles, birds, and mammals within the East Mojave, one can estimate relative abundance for many of the more obvious, diurnal species. Some groups such as snakes and carnivores will require further intensive study.

The Oak-Pinyon-Juniper habitat provides an excellent example of the predictive values of habitat analysis. Oak-Pinyon-Juniper was identified early in the study as an unusual, limited, and island-like habitat containing vegetation typical of southern California chaparral plant communities. Such plant species as canyon oak (*Quercus chrysolepis*), bush snapdragon (*Keckiella antirrhinoides*), silk tassel (*Garrya flavescens*), buckthorn (*Rhamnus ilicifolia*, *R. californica*), manzanita (*Arctostaphylos pungens*), and yerba santa (*Eriodictyon angustifolium*) were present. There were almost no museum or literature citations for the East Mojave in this habitat type. However, because of the vegetation, we predicted that faunal elements typical of southern California chaparral would occur there. Field surveys verified the predictions. An isolated and possibly relict population of the dusky-footed woodrat (Neotoma fuscipes) was discovered, and several species of breeding and wintering birds, typical of coastal chaparral, were noted.

SUMMARY

The system of habitat classification presented here has value for designing inventories, for identification of data gaps, and for use in making predictions on the distribution and abundance of vertebrates. It provides a data base from which priorities can be developed for future field surveys and research. It offers a simple means of evaluating, for land use decisions, the sensitivity of each habitat or area by both biologists and managers.

LITERATURE CITED

Berry, K.H., V.R. Remsen, Jr., and E. Wessman. 1976. Unit Resource Analysis for the East Mojave Planning Unit, Sections II and III Wildlife. California Desert Plan Prog., Bur. Land Manage., Riverside, California.

Cheatham, N.H. and J.R. Haller. In Press. An annotated list of California habitat types, In J. Major and M.G. Barbour (ed.), Terrestrial Vegetation in California. Wiley Intersciences.

Hansen, C.L., J.R. Huning, and A.S. Endo. 1976. Soils Inventory: East Mojave Unit. Rep. for California Desert Plan Prog., Bur. Land Manage., Riverside, California. Contr. 52500-CT6-1112.

James, F.C., and H.H. Shugart, Jr. 1970. A quantitative method of habitat description. Audubon Field Notes 24(6):727-736.

Johnson, D.H., M.D. Bryant, and A.H. Miller. 1948. Vertebrate animals of the Providence Mountains area of California. Univ. California Publ. Zool. 48:221-376.

Johnson, H. 1976. Unit Resource Analysis for the East Mojave Planning Unit, Sections II and III, Vegetation and Range. California Desert Plan Prog., Bur. Land Manage., Riverside, California.

Kubik, M.R., Jr., and J.V. Remsen, Jr. 1977a. 40th breeding bird census No. 128: Creosote-burrobush desert scrub. Am. Birds 30(1):76-77.

Kubik, M.R., Jr., and J.V. Remsen, Jr. 1977b. 40th breeding bird census No. 125: Catclaw-Rabbitbrush desert wash. Am. Birds 31(1):75-76.

Munz, P.A. 1974. A Flora of Southern California. Univ. California Press, Berkeley and Los Angeles.

Remsen, J.V., Jr. 1977. 40th breeding bird census No. 129:Desert riparian. Am. Birds 31(1):77.

Remsen, J.V., Jr., and K.H. Berry. 1976a. 29th winter bird population study 56: Desert riparian. Am. Birds 30(6):1063-1064.

Remsen, J.V., Jr., K.H. Berry, and E. Wessman. 1976b. 29th winter bird population study No. 51: Joshua tree woodland. Am. Birds 30(6):1060-1061.

Remsen, J.V., Jr., K.H. Berry, and E. Wessman. 1976c. 29th winter bird population study No. 54: Pinyon-juniper woodland. Am. Birds 30(6): 1062-1063.

Remsen, J.V., Jr., K.H. Berry, and E. Wessman. 1976d. 29th winter bird population study No. 52: Catclaw-rabbitbrush desert wash. Am. Birds 30(6): 1061.

Remsen, J.V., Jr., E. Wessman, and K.H. Berry. 1976e. 29th winter bird population study No. 49: Creosote-burrobush desert scrub. Am. Birds 30(6):1059.

Remsen, J.V., Jr., E. Wessman, and K.H. Berry. 1976f. 29th winter bird population study No. 48: Creosote-mojave yucca-cholla desert scrub. Am. Birds 30(6):1058-1059.

Thomas, J.W., R.H. Miller, H. Black, J.E. Rodiek, and C. Maser. 1976. Guidelines for maintaining and enhancing wildlife habitat in forest management in the Blue Mountains of Oregon and Washington. Trans. N. Am. Wildl. Nat. Resour. Conf. 41:452-476.

Thorne, R.F. 1976a. The vascular plant communities of California, pp. 1-31. In J. Latting (ed.), Symposium Proceedings: Plant Communities of Southern California. California Native Plant Soc. Spec. Publ. 2.

Thorne, R.F. 1976b. Plant communities in California's arid lands. Paper presented at Symposium on California Deserts: Dynamic Ecosystems. Sponsored by S. Calif. Botanists, 1 May 1976 at California State Polytechnic Univ., Fullerton, California.

APPENDIX A

MAPPING UNITS FOR SOILS AND LAND FORMS (43 UNITS)

DIS	DISTURBED AREA
1001	Scarp Front
1002	Rough and Broken Land
1101A2	Ephemeral stream, gravelly coarse sand, 0-3% slopes
1101A4	Ephemeral stream, stony coarse sand, 0-3% slopes
1201A2	Gravelly loamy sand, 0-3% slopes
1201A3	Cobbly loamy sand, 0-3% slopes
1201A4	Stony loamy sand, 0-3% slopes
1201-1204	
1202A2	Gravelly loamy sand, 0-3% slopes
1202A3	Cobbly loamy sand, 0-3% slopes
1202-1204	Association
1203A2	Gravelly sandy loam, 0-3% slopes
1204B2	Gravelly sandy loam, calcium carbonate dominant, 0-8% slopes
1204B3	Cobbly sandy loam, calcium carbonate dominant, 0-8% slopes
1204-1302	Association
1301B3	Cobbly loam, developed horizon, 0-8% slopes
1301-1204	
1302B3	Cobbly silt loam, developed horizon, 0-8% slopes
1302B4	Stony fine sandy loam, developed horizon, 0-8% slopes
1302-1201	Association
1302-1202	Association
1303A4	Stony silt loam, developed horizon, 0-3% slopes
1350A1	Playa, 0-3% slopes
1380B1	Loamy fine sand, eolian, 0-8% slopes
1381D1	Fine sand, dunes, 31-60% slopes
1382A4	Recent lava flow
1383B4	Pleistocene age lava flow
1401B2	Shallow, gravelly sandy loam, 0-8% slopes
1401-1402	Association
1402B2	Moderately deep, gravelly loamy sand, 0-8% slopes

1501B2	Gravelly sandy loam, 0-8% slopes
1601B2	Gravelly very fine sandy loam, 0-8% slopes
1701CD	Moderately deep, gravelly sandy loam, 9-60% slopes
1702CD	" " volcanic, 9-60% slopes
1703CD	" " igneous dominant, 0-60% slopes
1704CD	" " metamorphic dominant, 9-60% slopes
1705CD	" " sedimentary dominant, 9-60% slopes
1801DE	Shallow, gravelly loamy sand, 31-60+% slopes
1802DE	" volcanic, 31-60+% slopes
1803DE	" igneous dominant, 31-60+% slopes
1804DE	" metamorphic dominant, 31-60+% slopes
1805DE	" sedimentary dominant, 31-60+% slopes

V = Rock Outcrop

Slope

A	0-3%	nearly level
B	0-8%	gently sloping
C	9-30%	moderately steep
D	31-60%	steep
E	60+%	very steep

Surface Modifier

1 - none
2 - gravelly
3 - cobbly
4 - stony

PATTERN RECOGNITION AS A TOOL IN THE ECOLOGICAL ANALYSIS OF HABITAT

Gary L. Williams

Kenneth R. Russell

William K. Seitz

Colorado Cooperative Wildlife Research Unit
Colorado State University
Fort Collins, Colorado 80523

Abstract: Diagnostic procedures similar to those used by the medical profession to cope with uncertainty and risk are being developed to classify and evaluate wildlife habitats. Land tracts will be evaluated on the basis of their compositional and spatial patterns in relation to known wildlife species requirements and then classified according to relative population potential. The approach, based upon Bayesian statistical inference, is species specific and (1) defines in explicit terms how habitats are to be evaluated, (2) organizes existing knowledge about wildlife habitats and species requirements in a quantifiable manner, and (3) is sufficiently flexible to evaluate habitat suitability for a variety of species. The method may also be useful in assessing habitat-alteration impacts on populations and for developing habitat-improvement plans.

Aldo Leopold (1937:124) once remarked that the task of wildlife habitat assessment constituted one of the great enigmas of animate nature. Although Leopold made those comments 40 years ago, biologists today still lack a logical procedure through which they can inventory and make inferences about habitat suitability. In a world undergoing rapid alteration by both public works development and private enterprise, the ability to make intelligent decisions about wildlife habitat and their management may be among the most crucial problems confronting wildlife biologists.

If it is apparent that a habitat assessment methodology is needed, then it is equally apparent that whatever methodology is devised should satisfy certain basic requirements. First, the method should be easy to use and understandable to all potential users, both professionals and lay persons alike. Second, the method should go beyond mere classification; it should identify courses of action plus the ecological consequences associated with those actions. Finally, the method should posses ecological integrity and be simple but effective. In this paper, we propose a method of wildlife habitat assessment which we feel essentially meets these requirements. The method is based in part upon the emerging concepts of pattern recognition (Uhr 1964).

"Pattern recognition" is an activity or process that assigns meaning to one's experiences (classifies them) and can be subdivided into three distinct steps: (1) perception, (2) interpretation, and (3) decisionmaking. We believe these are the same fundamental steps a biologist uses when he assesses habitat and, as such, should be the basis of any formal approach to habitat assessment.

THEORY

If a biologist were asked, "How do you assess habitat suitability?", his explanation of the process might be as follows. "First I obtain ecological information about the area. Second, I evaluate the relative importance of each piece of information as it relates to the species of wildlife being considered. Finally, I decide on the basis of existing ecological conditions whether the area is likely to be suited or unsuited to meet the animal's requirements for food, water, cover, space, etc." This, obviously, is an oversimplification of the process because the biologist might also point out that, after inspecting the area, he has a certain "feeling" about it. That feeling represents the biologist's impression about how the individual pieces of ecological information fit together. It is his way of integrating several seemingly unrelated, independent pieces of information.

Granted, our example oversimplifies the biologist's thought processes. But it also demonstrates the pattern recognition process as it relates to habitat assessment. Habitat inventory (data gathering) is synonymous with pattern perception. The biologist interprets the significance of each piece of information by assigning a weight to it, although this may be done subconsciously. Finally, the "feeling" a biologist has about the area constitutes a decisionmaking step because he has decided how well suited the area is for the species of interest.

Certainly the biologist uses complex reasoning processes when he judges habitat conditions. But in spite of that complexity, there seems to be a formal structure underlying his actions. In making his assessment, the biologist seems to be saying, "If a certain condition exists, then it is likely that some other condition will also exist." For example, the biologist might reason that if an area provides suitable habitat for ring-necked pheasants (Phasianus colchicus), then it is also likely that suitable nesting cover will be available nearby. Finding suitable nesting cover, the biologist might next seek answers to questions about food availability or predator abundance. Many pieces of ecological information may be used in his final assessment. But, no matter how much information is taken into account, the biologist seems to have two mutually exclusive outcomes in mind (suitable habitat vs. unsuitable habitat) and he decides between these exclusive outcomes on the basis of the presence or absence of certain ecological conditions he knows from past knowledge and experience to be important.

Assuming the above scenario is a reasonable facsimile of how a field biologist judges habitat suitability, then we conclude that the biologist is basing his assessment upon personal conditional probabilities. This means that the biologist is expressing how certain he is about some condition (suitable pheasant habitat) after learning that some other condition (availability of nesting cover) is or is not also true. The probabilities the biologist uses are "personal" in that they are conditioned by everything he already knows about the event. Personal conditional probabilities are the probabilistic expression of learning from experience.

STATISTICAL METHODOLOGY

We believe the logical process of habitat assessment can be expressed as a problem in conditional probability. The problem consists of estimating the likelihood or probability that a particular area provides suitable habitat for a species, based on information about that area's ecological attributes. A useful tool, known as Bayes' theorem, exists for dealing with such statistical problems and constitutes the mathematical basis for our proposed habitat assessment scheme.

Bayes' theorem is named after a 17th century clergyman who first proposed this form of conditional probability. The mathematical theory upon which the theorem is based is presented in statistical textbooks such as Spurr and Bonini (1973). But since many biologists may not be familar with the theorem, a discussion of fundamentals seems to be in order.

The Bayesian technique involves three basic steps. The investigator: (1) estimates an initial probability distribution that some condition or set of conditions exist, (2) collects sample data, and (3) uses the sample results to revise his initial probability estimates into a final, decisionmaking distribution. As the technique is used in this paper, the sample information must have diagnostic properties, i.e., it must enhance the investigator's ability to differentiate between two or more closely related conditions.

The initial probabilities are often referred to as "prior probabilities" because they represent the investigator's best estimate for the occurrence of each condition prior to obtaining sample information. For similar reasons, the revised probabilities are called "posterior probabilities." Prior probabilities may be calculated from empirical data or they may be subjective estimates. Subjective prior probabilities do not necessarily lead to subjective conclusions because sample results and not prior probabilities have the most impact upon posterior probabilities. Prior probabilites mainly affect the posterior probabilities when (1) one or more of the conditions under consideration is much more probable than the others (i.e., occurs more frequently) or (2) sample data are meager.

The Bayesian technique requires that sample information be expressed as conditional probabilities. For example, the conditional probability of ecological condition E occurring in an area of suitable habitat (S) would be written as P(E/S) and read from left to right as "the probability of sample result E occurring given that the area is suitable habitat." Formally, P(E/S) represents the probability that sample result E would be obtained if suitable habitat conditions existed.

The derivation of conditional probabilities represents the key step in the application of Bayes' theorem. But this should not be viewed as a stumbling block in the application of Bayesian techniques to habitat assessment. In fact, the mathematical definition of a conditional probability reveals a basic consistency with the data collection process biologists use in the field.

The conditional probability $P(E/S) = \frac{N(E,S)}{N(S)}$

where N(E,S) is the number of suitable areas also having condition E. One can see from this expression that P(E/S) may be defined as a percentage or as a frequency. It is synonymous with the frequency with which ecological condition E occurs in areas of suitable habitat. To illustrate, if 10 areas of suitable habitat are inventoried and 3 are found to contain condition E, then P(E/S) = 0.30. Thus, conditional probabilities are merely a way of expressing inventory results.

The term "Bayes' theorem" actually refers to the formula with which prior probabilities are revised by the sample information. Various forms of the equation exist but a general form is:

$$P(S/E) = \frac{P(S)P(E/S)}{P(S)P(E/S) + P(U)P(E/U)}$$

where

$P(S)$ equals the prior probability of suitable habitat,

$P(U)$ equals the prior probability of unsuitable habitat,

$P(E/S)$ equals the likelihood of sample result E given suitable habitat,

$P(E/U)$ equals the likelihood of sample result E given unsuitable habitat, and

$P(S/E)$ equals the revised or posterior probability of suitable habitat given sample result E.

Although the form of Bayes' theorem cited above uses only two categories, suitable and unsuitable habitat, the formula could be expanded to include additional categories as long as those categories are mutually exclusive. A second important point is that our use of Bayes' theorem assumes statistical independence between individual observations in the sample. Thus, to use Bayes' theorem as we suggest, we must assume that information about the presence or absence of one ecological condition is of no value in predicting the probability of any other ecological condition used in the assessment. Given this cursory treatment of Bayesian statistical inference, we next describe how it might be used to develop habitat assessment models useful in the analysis of and decisionmaking about the habitats of individual wildlife species.

EXAMPLE

To illustrate how conditional probabilities might be used in habitat assessment, we have chosen to develop a hypothetical model of pronghorn antelope (*Antilocapra americana*) habitat requirements as they might exist in a grassland-sagebrush plant community in the northern Great Plains. Habitat requirements included in the example are based upon those provided by Yoakum (1975).

The model (Table 1) contains conditional probabilities associated with two levels of habitat suitability, high-density habitat and low-density habitat. We feel that describing habitat conditions in terms of relative density conveys more meaning than the abstract terms, "suitable habitat" and "unsuitable habitat," and also relates the model to a basic applied-management concern. While the habitat requirements included in the model are realistic, we stress that the conditional probabilities provided are *strictly hypothetical* and are not necessarily correct.

ASSESSMENT OF HABITAT SUITABILITY

Assume for the moment that you are a wildlife manager in the western United States with the responsibility of managing and maintaining antelope populations. You have ascertained from aerial photographs, field surveys, or other information sources that one of the areas you are managing has the following ecological attributes:

Table 1. Hypothetical Conditional Probability Model of Selected Habitat Requirements for Pronghorn Antelope in a Grassland-Sagebrush Plant Community

Habitat requirement	High-density habitat	Low-density habitat
Prior probability	0.40	0.60
Abiotic requirements		
A1. Area larger than 10 sq. mi. (16.09 sq. km)	0.95	0.85
A2. No barriers to movement	0.85	0.60
A3. Water available every 3-4 mi. (4.8-6.4 km)	0.99	0.20
A4. No prolonged snow accumulation exceeding 10 inches (25.4 cm)	0.95	0.15
Biotic requirements		
B1. Browse diversity (one only)		
No species common	0.05	0.40
1-5 species common	0.20	0.45
>5 species common	0.75	0.15
B2. Average browse height between 12 and 24 inches (30.5-61 cm)	0.65	0.40

1) Surface area exceeds 10 sq. miles (16 sq. km).

2) Barriers to movement do not exist.

3) Distance between water sources exceeds 4 miles (6.4 km).

4) Prolonged snow accumulations do not exceed 10 inches (25.4 cm).

5) Three species of antelope browse are common in the area.

6) Browse height averages 20 inches (50.8 cm).

Research biologists have ascertained from previous studies that each of the six parameters used in the evaluation have the potential to affect antelope densities. In some cases, the parameter may exert its influence through the food source (availability, quantity, or quality). In other cases, animal behavioral mechanisms may be involved. But, as a wildlife manager, your primary concern should be to interpret the combination of ecological conditions occurring within the area and assess their implications in terms of population potential. That task can be carried out mathematically using the conditional probabilities in Table 1. For example, in this hypothetical example the probability (likelihood) of obtaining the above inventory results (I) given the area has a high population potential is:

$$P(I/H) = (0.95)(0.85)(1.0-0.99)(0.95)(0.20)(0.65)$$

$$= 0.00099$$

and given the area has a low population potential is:

$$P(I/L) = (0.85)(0.60)(1.0-0.20)(0.15)(0.45)(0.40)$$

$$= 0.01102$$

Notice from the above calculations that the conditional probabilities (Table 1) are used only when the corresponding habitat requirement is satisfied. When a particular requirement is not satisfied (water distribution in our example), the probability used in the calculations equal 1.0 minus the listed probability (for water distribution 1.0 - 0.99). This is an important point because knowing that a particular habitat requirement is not satisfied may reveal more about habitat suitability than knowing that the requirement is satisfied.

The numbers calculated above represent the probabilities of obtaining the inventory results if the area had high and low population potential respectively. Considered individually, the two probabilities are meaningless. But they can be used to calculate an "expected habitat suitability" (EHS) index. If we define EHS as the probability of high-density habitat, then we apply Bayes' theorem to calculate

$$EHS = \frac{P(H)\ P(I/H)}{P(H)\ P(I/H) + P(L)\ P(I/L)}$$

$$= \frac{(0.4)(0.00099)}{(0.4)(0.00099) + (0.6)(0.01102)}$$

$$= 0.06$$

In essence, this computation "interprets" the perceived ecological pattern by revealing a 6 percent probability that the area has the resources to maintain high population densities. The area may in fact have that capability but it is not very likely. On the other hand, the computation also reveals a 94 percent probability (1.0 - 0.06) for a low-density situation.

In addition to interpretation, the above calculation also provides a basis for decisionmaking. Based strictly upon probabilistic considerations, the area should be classified as low-density habitat. For species as visible as pronghorn antelope, the classification could be easily verified through field census. But for less visible species, field verification might be more difficult.

INFERENCES ABOUT DENSITY POTENTIAL

The revised probabilities calculated above could be converted to population density estimates by employing the "expected value" technique (Spurr and Bonini 1973). Discussion of the mathematics behind the technique is not particularly germane to the present paper so suffice it to say that the expected value technique corresponds to that of a weighted average, with probabilities serving as the weights. Given the discrete values X_1 and X_2 and the probabilities of those values $P(X_1)$ and $P(X_2)$, the expected value of X is given by:

$$
\begin{aligned}
E(X) &= \Sigma[X \cdot P(X)] \\
&= (X_1)\,P(X_1) + (X_2)\,P(X_2)
\end{aligned}
$$

It would be informative to discuss this calculation in terms of the antelope example presented above.

Field surveys by the Colorado Division of Wildlife (1977) revealed a statewide antelope density of about 0.77 antelope/mi^2 during 1972 and 1973. The areas of highest density averaged about 5.4 antelope/mi^2 whereas the areas of lowest density averaged about 0.15 antelope/mi^2. If the above antelope model were based upon those high and low values, the inventoried area would have an expected density potential of:

$$
\begin{aligned}
E(D) &= 0.06(5.4) + 0.94(0.15) \\
&= 0.32 + 0.14 \\
&= 0.46 \text{ antelope/mi}^2 \ (2.59 \text{ km}^2)
\end{aligned}
$$

The reader should understand that this is a crude estimate of the long-term mean density in the area. The estimate is valid only so long as habitat conditions remain essentially unchanged. Furthermore, the actual population density may be above or below the computed value at any given point in time. But expectation values would appear to be the most expedient method of making inferences about density potential from habitat inventories. This is not to say that there may not be other, more accurate techniques which use similar types of data.

HABITAT MANAGEMENT AND MAINTENANCE

To be most flexible and therefore provide for the broadest possible use, we believe a habitat assessment method should do more than merely assign a name or numerical rating to a given landscape pattern. It should also identify courses of action to follow to improve the animal's habitat. This capability is provided by the pattern recognition approach when the probabilities associated with individual habitat requirements are reviewed and carefully analyzed.

The six habitat requirements listed in our hypothetical model for pronghorn antelope are summarized in Table 2. You will notice that the probabilities shown in Table 2 are the same as those derived from inventory results. But also notice that the six probability sets provide a diagnostic capability when examined individually. For example, notice that the P(I/H) values exceed the attending P(I/L) values in all sets except two. Conditions existing with respect to habitat requirements A3 (water distribution) and B1 (browse diversity), are more indicative of low density than high density habitat. The area may not provide optimal conditions with respect to any of the six requirements. However, if a program of habitat improvement were undertaken, the most logical place to begin would be with respect to water availability and browse diversity since these appear to be the most severely limiting conditions.

Table 2. Use of Conditional Probabilities to Identify Courses of Management Action and to Set Priorities

Step	Habitat Requirement					
	A1	A2	A3	A4	B1	B2
LIST PROBABILITIES						
P(I/H) values	0.95	0.85	0.01	0.95	0.20	0.65
P(I/L) values	0.85	0.60	0.80	0.15	0.45	0.40
CALCULATE WEIGHTS[a]						
	0.10	0.25	-0.79	0.80	-0.25	0.25

ASSIGN PRIORITIES

A3 = Water Distribution = Priority 1

B1 = Browse Diversity = Priority 2

---

[a] Weights are calculated by subtracting P(I/L) values from P(I/H) values.

Biologists must frequently face the stark reality that they do not have unlimited funds and manpower at their disposal to manipulate habitat. They must set priorities on the basis of anticipated returns from their actions. The probabilities (Table 2) can be used to set management priorities in the following manner.

At this point, we have identified two habitat conditions in need of attention, water distribution (A3) and browse diversity (B1). Operating with limited resources, the important question becomes "Which habitat condition do we manage first?". We suggest that management priorities can be established by analyzing magnitude of difference between the probabilities for each habitat requirement. The differences in probabilities (Table 2) in effect assign a "weight" to each habitat requirement. To illustrate, the weight of habitat requirement B1 (browse diversity) is 0.20-0.45=-0.25. But the weight associated with habitat requirement A3 (water distribution) is 0.01-0.80=-0.79. Assuming the presence of manpower and funding limitations, the most logical course of action to pursue first would be to improve water availability in the area since that course of action would be expected to yield the greatest returns in terms of EHS (Table 3).

Table 3. Anticipated Consequences of Manipulating Opposing Habitat Features

Management priority	Habitat feature manipulated	Consequences (revised EHS)[a]
1	A3 (water distribution)	0.96
2	B1 (browse diversity)	0.40

[a] These values compare to an EHS without any management attention of 0.06.

ADDITIONAL CONSIDERATIONS

In addition to providing a logical mechanism for assessing habitat suitability and setting management priorities, we feel the approach outlined herein will provide additional benefits to the science of wildlife management. Two of those additional benefits deal with standardization and communication.

STANDARDIZATION IN HABITAT ASSESSMENT

One of the major difficulties biologists experience when assessing habitat conditions is absence of established standards for comparison. When a biologist assesses an area, he/she is essentially comparing that area to other areas observed in the past. Thus in a certain sense, the biologist is attempting to use mental models or "mental standards" in the process, mental standards which often are fuzzy, ill-defined, and variable from biologist to biologist.

Standards are needed which will allow a biologist to evaluate an area in the future with the same general criteria and level of objectivity used today. Habitat assessment models would provide a step in this direction. The models would essentially establish standards which summarize existing knowledge and experience, standards which can be added to and refined as our ecological knowledge of the species increases. In addition, after being developed and field tested, the models could be made available to all biologists working with that particular species under similar ecological conditions.

IMPROVED COMMUNICATION BETWEEN MAJOR ENTITIES

The accumulation of additional ecological knowledge is certainly a desirable and worthwhile undertaking. But unfortunately, a biologist's potential for integrating that knowledge is limited. Integrating new information into assessment or management programs will become increasingly more difficult unless methods for arranging and presenting research findings are discovered. Habitat models based upon conditional probabilities could be an effective tool in this respect. Such models would allow the biologist to interpret his field data rapidly and make recommendations to middle- and upper-level decisionmakers with respect to alternative courses of action and their anticipated ecological consequences.

MODEL DEVELOPMENT

It seems apparent that the modeling approach proposed in this paper would have to be based upon regional considerations since the habitats and densities of wide-ranging species often vary between geographic areas. The models would have to take into account seasonal habitat needs and be used only in areas vegetatively and climatically similar to the areas in which they were developed.

A regional approach would also provide a basis for setting prior probabilities. Bear in mind that prior probabilities are in a sense "background" information and are not based upon ecological conditions at any particular site. Thus, prior probabilities could be estimated by the investigator after considering such region-wide features as land-use practices or human population density.

Conditional probabilities included in the models could be based upon expert judgment. Personal opinion may be an expedient way of developing a preliminary assessment model. However, our feeling is that the conditional probabilities should reflect actual frequencies to the extent possible. Areas of known high and low population potential within the region should be identified and inventoried to ascertain the frequency of occurrence of each habitat parameter included in the model.

APPLICATIONS

To the best of our knowledge, the method of habitat classification and analysis discussed in this paper has not been attempted in wildlife management and therefore represents an untested technique. But the philosophy upon which the method is based is similar to that used in mathematical medical diagnostic procedures (Lusted 1968). Diagnostic models based upon conditional probabilities have been in various stages of development by the medical profession for at least 20 years and seem to be playing an increasingly important role in diagnosing human diseases.

There seems to be a variety of potential applications for diagnostic models in wildlife management. In addition to habitat assessment, such models might prove useful to the biologist in such areas as habitat impact assessment and the selection of release sites for threatened and endangered species. In these respects diagnostic models may become as useful in wildlife management as they are in medicine.

LITERATURE CITED

Colorado Division of Wildlife. 1977. Antelope Inventory Results. Denver, Colorado.

Leopold, A. 1937. Game Management. Charles Scribner Sons, New York. 481 pp.

Lusted, L. B. 1968. Introduction to Medical Decision Making. Charles C. Thomas, Springfield, Illinois. 271 pp.

Spurr, W. A., and C. P. Bonini. 1973. Statistical Analysis for Business Decisions. Richard D. Irwin, Inc., Homewood, Illinois. 724 pp.

Uhr, L. 1964. Pattern Recognition. IBM Medical Symp. 6:305-323.

Yoakum, J. D. 1975. Antelope and livestock on rangelands. J. Animal Sci. 40(5):985-992.

Session IV

Inventory Methodology And Information Management Systems

INVENTORY AND DISPLAY OF AQUATIC HABITAT

Albert W. Collotzi
U. S. Forest Service
R-10, Pouch 6606
Anchorage, Alaska 99502

Donald K. Dunham
Intermountain Region
U. S. Forest Service
324 25th Street
Ogden, Utah 84401

Abstract: A systematic and uniform approach to the inventory and display of the aquatic habitat has been developed in the Intermountain Region of the U.S. Forest Service. A line transect method is used to measure habitat variables. A rating score for stream habitat variables is displayed for interpretation and analysis by the biologist. A land classification system for the valley bottom lands provides for the display of the aquatic resource at various levels for planning and all associated resources can be inventoried and evaluated on an equal basis.

INTRODUCTION

Fish population surveys have been conducted on many waters of the United States. Geographic ranges of fish species are fairly well known, or at least predictable, and there are management programs to perpetuate and enhance these resources.

The habitat resource available to, utilized, or occupied by these species is less well known with precision and accuracy. The cause and effect relationship of man's activities, which directly or indirectly affect the characteristics of the habitat, is poorly understood. To improve our understanding of the aquatic resource, and as a means to avoid ocular or eyeball appraisal, a method for sampling general fish habitat characteristics of streams was investigated beginning in 1960 (Herrington and Dunham, 1967). Since 1960, the basic method (later known as the transect method) has been tested and expanded into systems that have been applied to in stream flow needs, baseline inventory, project work, and land use planning. The systems do not singularly measure biomass and fish production, but are designed to inventory and display fish habitat characteristics at different intensities in order to fit the needs and purposes of a given level of planning. If the level of planning is broad, the level of inventory must be broad. If the level of planning deals with a specific project, then the inventory must be more specific (Dunham and Collotzi, 1975).

Bailey (1976) in his work "A Regional Approach to Ecosystem Classification for Purposes of Resource Inventory--An Initial Effort," emphasizes the need for a hierarchical system which permits a choice of the degree of detail required to meet the purpose of a particular planning or decision level. Arnold (1975) presented a similar view and recognized that such a system was needed for aquatic and wildlife resources. The problems associated with classifying aquatic and wildlife resources are no different in principle than those found in other resources.

The approach presented by Collotzi (1976a) emphasizes the importance of the valley bottom as a recognizable unit of land. Since then, the approach has been refined and expanded to include a total system which allows all disciplines to relate to the valley bottom.

In most inventories, the valley bottoms have not been mapped. Therefore, the lesser stream bottom lands were often overlooked in the larger land masses. "Valleys include some of the most sensitive portions of the landscape insofar as their response to disturbance. They are also the part of the landscape that receives the greatest use by man. We build most of our roads, trails, campgrounds, and buildings in the valleys. Many species of wildlife and fish are dependent for at least part of their annual life cycle on mountain valley habitat. Stream and water qualities are determined to a great extent on what takes place in the valleys. Land use planning must recognize and provide for the qualities of valleys if management is to achieve its objectives." (Cole 1972:4.)

The concern for inventory and display of habitat is a logical reflection of the Forest Service's responsibility and interest in the aquatic resource. Since 17 April 1941, the desire for more definitive habitat programs has been clearly recognized within the Forest Service; its Chief, jointly with officials of the International Association of State Fish and Game Commissioners, defined a partnership role with states to conduct wildlife management on National Forests (36 CFR 241.2). The Multiple Use and Sustained Yield Act (Public Law 86-517 74 Stat. 215) states, "That it is the policy of the Congress that the National Forests are established and shall be administered for outdoor recreation, range, timber, watershed, and wildlife and fish purposes." Section 2 of this Act states, "The Secretary of Agriculture is authorized and directed to develop and administer the renewable surface resources of the National Forests for multiple use and sustained yield of the several products and services obtained therefrom." The valuable wildlife and fish habitat provided and the outdoor recreation furnished by the lakes and streams of the National Forests make these among the most valuable areas under Forest Service administration. The Forest Service, because of legislation by Congress, is responsible for maintaining and, where possible, improving the renewable resources of these high value land and water areas.

INVENTORY METHOD

The inventory is a sampling procedure using cross-channel tape-measured lines termed transects to quantify habitat variables. Measurements are made along a transect across the stream channel at a 90° angle to its centerline. The basic assumptions of the method are: (1) that by applying the transect method, key habitat variables related to production of aquatic organisms can be inventoried and displayed; (2) that the transect method can be used to measure variation of physical features within and between streams; and (3) that stratification of the valley bottom provides for the interaction of the aquatic resource with other resources by recognizing units of land that are mappable, describable, and predictable.

Three habitat categories of water surface, stream bottom, and stream banks are recognized. Habitat variables are identified, classified, and by following directions on the field forms, qualitative/quantitative classifications and measurements are recorded for each of the following categories:

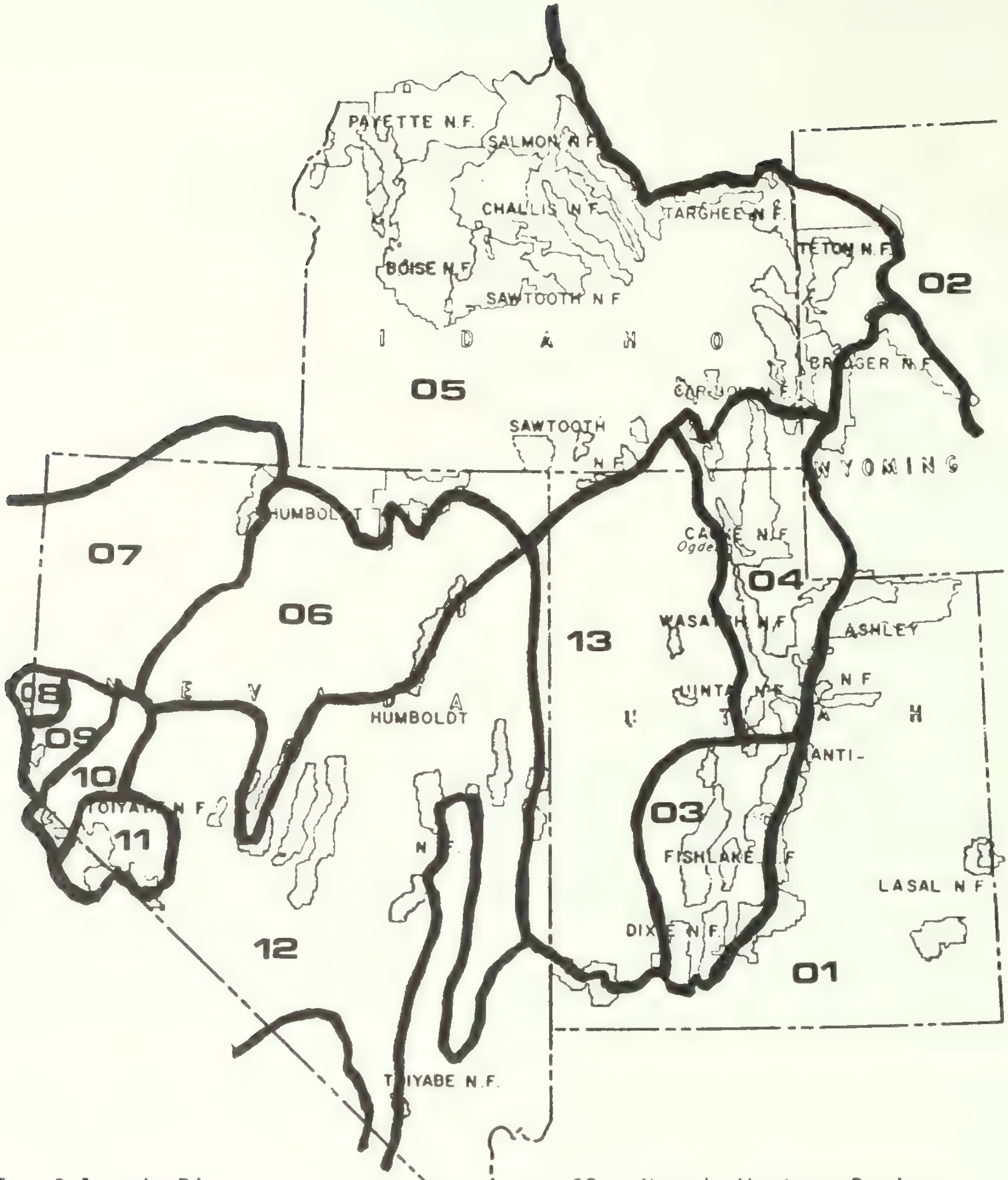
- Water surface
    - Pools
    - Riffles (classification being developed)
    - Depth
    - Flora
    - Velocity

- Streambottom
    - Size gradations
    - Imbeddedness (classification being developed)

- Streambanks
    - Riparian vegetation
    - Stability
    - Soil class

Survey work consists of sample data either from a one-transect station or data grouped from a five-transect line station. The five-transect line station will provide data for a cluster sample. These transects originate at 20 m intervals along a streamside base line which is established for this purpose. Both procedures will give results which characterize the habitat, but cluster sampling is advantageous because it: (1) characterizes habitat within the 80 m length of channel; (2) can be used to make inferences about habitat within the stream segment; (3) requires fewer samples to adequately describe a drainage, an individual stream, or a stream segment; and (4) facilitates use of statistics designed for normally distributed populations.

The entire program has computer capability (Collotzi, 1976b). The General Aquatic Wildlife System (GAWS) is designed to serve the dual purposes of (1) storage-retrieval without additional data manipulation and (2) storage-retrieval with data manipulation through output programs which compute habitat ratings, streamflows, statistical measures, and standard descriptive features. All field forms are geared to input-output formats. An identification code for each water is the key to using the program. The Intermountain Region has established an identification system similar to those used by the fishery agencies of Utah and Idaho. The system is systematic, uniformly applicable, and readily understood. Each stream is assigned a number based on the drainage and tributary sequence (Figure 1). Regardless of the number of creeks having the same name in the Intermountain Region, the system will locate each stream in a specific geographic location.



01 - Colorado River
02 - Missouri River
03 - Sevier Lake Tributaries
04 - Great Salt Lake and Utah Lake Tributaries
05 - Snake River
06 - Humboldt River
07 - Quinn River
08 - Nevada Western Region
09 - Truckee River
10 - Carson River
11 - Walker River
12 - Nevada Central Region
13 - Utah-Nevada Desert Region

Figure 1. Main drainage code, Intermountain Region, U.S. Forest Service.

Prior to entering the field, streams to be inventoried are mapped using aerial photographs and geologic survey maps or other appropriate maps, preferably 1:31,680 scale. Convenient strata are outlined and sample stations determined on these maps or photographs.

An action plan which includes inventory specifics and expected use of survey data is written to assure accomplishment to the desired level of precision and accuracy.

The field crew locates points on streambanks that coincide approximately with the sample station points marked on the aerial photos or maps. Possible bias is eliminated by having the crew establish the first transect a given distance upstream from the point first identified on the ground.

Procedures to inventory lakes, reservoirs and potholes, by use of transects, are under development and evaluation.

DISCUSSION

Data collected in this systematic manner has several uses. After several schemes were employed to display and apply habitat data, computational procedures were chosen which result in a rating or score for habitat variables. The concept of a habitat rating is similar in appeal to the stream rankings, prepared by many of the states, which emphasize fishing and fish production aspects of the resource. However, this habitat rating does not consider production levels, access, angling success, and similar factors. Analysis is not restricted to the ratings and reporting includes associations with valley bottom, discharge and in stream flow, fish species, landforms, and localized project impacts.

Habitat data of each sample are rated (each component has a potential of 100) in four components defined as follows:

1. Pool Measure. A rating of pool and riffle habitat.

2. Pool Structure. A rating of poor quality.

3. Stream Bottom. The percent of gravel and rubble bottom.

4. Stream Environment. A rating of streambank vegetative cover, in order of trees, brush, grass-forbs, and exposed.

A final Percent of Optimum is the average of the habitat component ratings. National Forest streams rated in this manner (Table 1) illustrate the range in Percent of Optimum for the Intermountain Region.

Table 1. National Forest Streams Rated for Habitat Variables

Stream	State	Av. width ft.(m)	Percent of optimum
Fish creek	Wyoming	16 (4.9)	64
Montpelier creek	Idaho	13 (3.9)	62
Fifth water	Utah	8 (2.4)	51
Trail creek	Idaho	18 (5.5)	50
Diamond fork	Utah	22 (6.7)	49
Sixth water	Utah	15 (4.6)	48
Currant creek	Utah	21 (6.4)	46
Wolf creek	Utah	8 (2.4)	44
Moose creek	Idaho	27 (8.2)	44
Rock creek	Utah	40 (12.2)	41
Salina creek (highway)	Utah	19 (5.8)	40
West fork duchesne	Utah	22 (6.7)	40
Game creek	Idaho	17 (5.2)	39
Taft creek	Nevada	7 (2.1)	37
Salina creek (control)	Utah	20 (6.1)	35
North fork duchesne	Utah	36 (11)	33
Hades creek	Utah	10 (3)	25

Habitat inventories will result in a display of the habitat components for interpretations and analysis (Table 2). As expected, however, an analysis of habitat components will demonstrate variation by stratifications within a stream or between streams, between valley bottoms, and between geographic areas. For example, streams with similar Percents of Optimum may actually exhibit different combinations of habitat components. By displaying the inventory results, the biologist can describe this difference or similarity between streams and prescribe management which will protect or enhance the aquatic resource.

Land use planning has necessitated the development of a system to display aquatic resources for comparison with other resources. The valley bottom concept provides for this comparison and a way to incorporate the various resources into several levels of planning. A compatible hierarchical system for the valley bottoms has been developed. This system includes four levels starting at the Subsection (Table 3). The most important level in the hierarchical system is the Valley Bottom Association.

In the past, only a part of the valley bottom has been identified as an association; these large units were classed as Depositional Lands (alluvial deposits) by the soil scientists. The many smaller units were not mapped. Valley bottoms outside of the Depositional Lands were then used only as boundaries between other associations. The proposed new system recognizes that all valley bottoms can be stratified into logical associations. This systematic approach to the stratification of the valley bottom, for the first time, allows all resources within the valley bottom to be evaluated simultaneously on an equal basis with other resources and land management activities. In addition, the land manager and biologist can easily recognize these associations.

Three Valley Bottom Associations have been described and a fourth is being considered. One of the primary differences between these associations is stream gradient. Each can be easily identified in the field using a hand level. If field time is limited, the associations can be mapped using resource photographs (1:15,840) and Geological Survey Maps (7.5 minute series-topographic). Field checks can be made later.

Stratification of the valley bottom into these associations has identified some of the variability in the aquatic habitat. An analysis of 732 pools provided the following information. Nearly 50 percent of all the pools were located in the Low Gradient Association including 60 percent of the Class 1 rated pools, and 63 percent of the Class 2 pools, and 57 percent of all beaver dams. Pools associated with boulders are generally the poorest quality pools; 49 percent of the pools in the Steep Gradient Association are associated with boulders. A general description of these associations follows.

VALLEY BOTTOM GRADIENT TYPES

Steep Gradient Valley Bottoms

These valley bottoms are associated with stream segments having an overall gradient better than 3 percent and nearly all are located outside of Depositional Lands. The bottoms are generally narrow with steep slopes on either side. The action of the streams is one of cutting and transporting of materials to other gradient types. Soils are commonly shallow, forming a thin mantle over bedrock

Table 2. Tally of Rating Scores for Habitat Components from 94 Cluster Sample Stations Chosen at Random

Rating percent class	Pool measure	Pool structure	Stream bottom	Stream-banks	Habitat percent of optimum	Streambank stability
0	7	31				6
1-9	2	5	4			2
10's	8	17	5			4
20's	10	15	9	3	5	4
30's	15	5	6	9	24	2
40's	16	6	6	6	34	5
50's	7	3	11	16	15	3
60's	7	3	16	19	8	2
70's	5	2	13	31	6	3
80's	8	5	17	3	2	4
90's	7	2	7	6		5
100	2			1		12
Total	94	94	94	94	94	58

Table 3. A Hierarchy for the Valley Bottom Stratification

Name	Defined as including
IV Subsection	Major lithological areas such as granite, hard and soft sedimentary formations, gross morphology, and kinds of process, etc.
III Valley bottom association	Valley bottom type as determined by gradient.
II Valley bottom type	Group of neighboring units with a valley bottom, such as stream, alluvial fan, terrace, lake, etc.
I Valley bottom phase	Vegetative or community type, pools, or riffles, beaver pond, etc.

and support a variety of plant communities, including birch/dogwood, mixed conifer/shrub and/or aspen/shrub, and narrow strips of willow/sedge. Most of the slopes, depending upon the aspect, support a conifer-type community or a sagebrush/aspen,forb/grass type.

Intermediate Gradient Valley Bottoms

Valley bottoms are associated with streams having an overall gradient between 2 to 3 percent. Materials carried by the streams are being deposited and being removed from the valley bottom. Most of the bottom soils were deposited at an earlier time, primarily as a result of glacial activity. Stream channels are generally banked by old depositional gravels and sandbars with rubble-size rock fragments. Streambanks and the alluvial bottoms are often flooded during spring runoff, but dry out quickly as summer progresses. The soils are deep and support a variety of plant communities including willow/sedge/grass, birch/dogwood, spruce/dogwood and equisetum, and in the drier sites, sagebrush communities with scattered and small patches of conifer.

Low Gradient Stream Valley Bottoms

These valley bottoms are associated with streams having an overall gradient <2 percent. Materials carried by the stream are being deposited in the valley bottom, resulting in the development of wide floodplains. Stream channels are banked by depositional gravels and sandbars. Most of the streambanks, and 60 to 70 percent of the alluvial bottoms are wet and subject to periodic flooding. Deep soils support a willow/sedge/grass community in the wet areas and sagebrush communities with scattered, small patches of conifer on the drier sites.

CONCLUDING COMMENTS

Habitat work in aquatic wildlife is rapidly accelerating in the Intermountain Region of the Forest Service. Methodologies, criteria, and standards are evolving and for the first time, will provide the line manager with an accurate description of the habitat resource. Formerly, there had not been an adequate display of the aquatic resource within a logical classification system that successfully considered all resources simultaneously and on an equal basis. The valley bottom classification system provides for the interaction of all resources within the valley bottom. The aquatic environment within the valley bottom is inventoried and characterized using the transect method. The level of planning determines the intensity of the inventory.

LITERATURE CITED

Arnold, J.F. 1975. The Idaho Batholith-a Sourcebook of Information. Intermountain Region, U.S. For. Serv. 290 pp.

Bailey, R.G. 1976. A Regional Approach to Ecosystem Classification for Purposes of Resource Inventory-an Initial Effort. Preliminary review draft. Intermountain Region, U.S. For. Serv., Ogden, Utah. 41 pp.

Cole, G.F. 1972. Valley Types-an Extension of the Land Systems Inventory to Valleys. U.S. For. Serv., Boise Natl. Forest, Boise, Idaho. 14 pp.

Collotzi, A.W. 1976a. A Systematic Approach to the Stratification of the Valley Bottom and the Relationship to Land Use Planning. U.S. For. Serv., Jackson, Wyoming. 17 pp.

Collotzi, A.W. 1976b. The General Aquatic Wildlife System. U.S. For. Serv., Intermountain Region, Ogden, Utah. 34 pp.

Dunham, D.K., and A.W. Collotzi. 1975. The Transect Method of Stream Habitat Inventory: Guidelines and Application. U.S. For. Serv., Intermountain Region, Ogden, Utah. 98 pp.

Herrington, R.B., and D.K. Dunham. 1967. A Technique for Sampling General Fish Habitat Characteristics of Streams. U.S. Dept. Agric. For. Serv., Intermountain For. and Range Exp. Sta., Res. Pap. INT 41, Ogden, Utah.

INTEGRATION OF OPERATIONAL REMOTE SENSING SYSTEMS WITH CONVENTIONAL INVENTORY PROCEDURES

H. Dennison Parker
U.S. Fish and Wildlife Service
Federal Building
Fort Collins, Colorado 80521

Abstract: Remote sensing applications to resource management must be made with data specifications and requirements in mind, since the technology is only a tool. It is best suited to the acquisition of inventory data, although it cannot fill all resource inventory needs. LANDSAT data is appropriate for regional data, but certain limitations of the satellite data acquisition systems must be understood to take best advantage of them. For more detailed information, aerial color infrared imagery offers numerous advantages. The integration of remote sensing and other types of data must occur in a computer-based geographic information system if future resource management demands are to be met.

In the introductory chapter of the third edition of the Wildlife Techniques manual, Robert Giles, the book's editor, made the observation that there was ... "newcomer to the research scene: a solution in search of a problem" (Giles 1969:3). Now, before that concept blows any minds let me hasten to add that I, and presumably Dr. Giles, am not suggesting abandonment of a scientific approach to research, or of conventional research and management techniques. I am suggesting that new technologies should be examined for possible application as wildlife and ecological research tools, and that we must actively pursue such applications, if they are to be found. The infusion of new technologies into wildlife management and research will not occur spontaneously. New technology in other fields is proceeding too rapidly to expect it to somehow passively percolate into the substrata of traditional ecological and wildlife management without considerable encouragement.

There has been much interest recently among both Federal and state agencies in a new technology called remote sensing. I would like to suggest some ways in which this technology might be integrated with conventional procedures of resource management, it is hoped, for the improvement of that management.

Before discussing this integration, I should define some terms for discussion purposes. Everyone is aware that remote sensing, as opposed to proximal sensing, generally refers to methods of obtaining information about some surface or physical matter without physical contact. At the same time, the phrase "conventional inventory procedures," probably conjures up images of a field biologist tramping across the sagebrush writing strange symbols and combinations of letters on a form.

But, what is conventional? Aerial photography has been used since the late 1930's, at least to a limited degree, for range investigations (Moyer 1950). Obviously, a technique which has been used for over 30 years must be considered conventional. Although the imagery used was crude by comparison with today's imagery the process nonetheless fits our definition of remote sensing. However, there are other types of aerial sensing which unquestionably justify a title of "unconventional." For simplicity in discussion, I shall refer to all ground procedures as being conventional, and will reserve the term "remote sensing," for aerial procedures.

There have been numerous research efforts, many papers, and endless arguments generated over the application of remote sensing techniques to ecological field investigations. Perhaps the remote sensing community has been overanxious in their attempt to exploit this new technology, because some field biologists have been "turned off" rather than welcoming them with open arms. If remote sensing techniques have not been grandly successful in ecological applications, I believe it is due to the difficulty of the tasks to which they were applied. The structures and functions of natural ecosystems are extremely difficult to analyze and define. We need consider only the myriad different approaches to ground investigations of habitat to appreciate that not all ecologists are in agreement on even these "conventional" approaches. It is not surprising that most agencies with range or wildlife habitat management responsibility have different sets of techniques for inventorying the resource. Further, if you proceed from one major ecosystem to another, you will probably find the same techniques are not suitable to both. Clearly the problems of ecological systems are not simplified by the technology used.

Unfortunately, remote sensing is no Santa Claus. Although some remote sensing technologies are complex and powerful, the tasks we must ask them to perform in ecological investigations are even more complex. But, lest we throw out the baby with the bath water, we should recognize and appreciate these new tools for what they are and for the contributions they can make.

The title of this paper is particularly meaningful. Notice, it does not say "replacement of conventional inventory procedures with remote sensing methods." Although the concept of integrating remote sensing technologies with older methods may seem trivial, it represents a significant departure from the approaches taken in the past by many investigators who have tried to answer multitudes of questions simultaneously with remote sensing technology. I am convinced that integration is the key to successful application of the technology. At the same time, I have no cookbook nor even solid proof that such integration can be successful. But, based on a few years' experience, a lot of frustration, and debates with other similarly frustrated minds, I do have a few suggestions. Before discussing specific remote sensing applications, I would like to address briefly the general subject of data requirements.

The most basic consideration in planning for field data acquisition of any type is to first specify in detail exactly how the data will be used; what are the objectives of the planned action which initiated the data requirement? In research, the same advice is appropriate although it may be couched in different terms such as "complete your experimental design before you get your data." Somehow, in resource management this step is frequently omitted, resulting in the generation of large amounts of field data of which analysis is not possible, let alone planned. Of course, the reverse problem is common also. Perhaps everyone has at some time been in need of more data then he has, or has time to obtain.

A related consideration involves the economics of the problem. How much time and money can we put into the data acquisition effort? Even if we know what data is required to properly do the job, can we realistically expect to get it? In many cases, the answer is no. But, increasingly, the option of employing remote sensing techniques is creating an economic reality where conventional procedures were out of the question.

After the purpose, budget, and time schedule for data acquisition have been clearly established, the user is able to define the data specifications and consider various methods for its acquisition. Ideally, the required data would be specified before any consideration of time and budget, but, as a practical matter, it is a rare project that is not constrained by at least one and usually both of these factors.

In specifying data requirements, it is elementary that the data acquired must match the available technological and scientific capability to analyze it. Elementary though this consideration may seem, it is neither trivial nor necessarily guaranteed to be made. How many reports have you seen that presented field data in large tables without any attempt at analysis? Or, if superficially analyzed, then without consideration of the data's meaning in terms of the total ecosystem? Although some such reports may be incomplete because of time constraints or oversight, I think more often the authors just do not know what to do with the data to give it meaning. Sometimes this error is due to ineptitude. But, more often, I think, it results from merely a lack of ecological knowledge of the scientific community in general; the "state of the art" is not sufficiently advanced. If the data cannot be explained, should time and money be expended to obtain it in a resource management context?

The scientific capability for data analysis can be considered a reflection of the current state of the art in regard to our knowledge of ecological structure and function. There is not much we can do to advance this state of the art in a resource management context. However, we can take advantage of the advances of others and we have only ourselves to blame if we do not. It is perhaps axiomatic that proven research results will not see field implementation for a decade or more. I would even go so far as to say this has been some kind of "natural" law in resource management. In fact, we in ecological endeavors have a "state of the art," and a "state of the practice," the former leading the latter by decades. I do not think this lag has to be so long; other scientific disciplines have cut it considerably. Practitioners have not only caught up with research, they have even pushed it ahead of them like a bull elk his harem. I do not have a solution for the problem of technology lag in ecology. But somehow that "natural" law must be broken to get the true ecological state of the art into practice. It has been broken in other fields, such as engineering, and we are severely handicapping ourselves by not breaking it in ecology.

After the data specifications have been completed, and the tools for meaningful analysis are available, the data acquisition procedures can be specified. To illustrate some specific approaches to the integration process, consider an area 100 by 100 miles (161 Km^2) in size, within which are located numerous small development sites. The impending developments may be coal mining operations, reservoir construction, stream channelization, a power or synthetic fuels plant, or any of numerous other potential resource uses which will result in a changed environment. Assume also that there is sufficient time to "get ahead of the game", by having available enough information to render early and defensible opinions on the ecological impacts of the proposed developments. I would like to lead you through the process of environmental data acquisition and illustrate some of the ways in which remote sensing and conventional survey methods may be applied to obtain the necessary data. I will digress from the scenario occassionally to discuss the rationale and technical considerations involved in each remote sensing application presented. I will also concentrate on wildlife-related problems and examples.

The obvious first place to begin is with a thorough search for existing data. Although some of it will be old, incomplete, or technically unsound, we still must locate and examine it to avoid unnecessary duplication. For illustrative purposes, let us assume for the moment that no existing information is uncovered, and that we literally must start from "scratch."

Given the task of assessing and monitoring the impacts of various developments in our hypothetical region, the obvious first requirement is an inventory. But, I do not mean inventory only in the sense of counting acres, or animals, or streams, or any other single attribute of the landscape, although such data are also important. Perhaps of more importance than the absolute amounts of features in various categories, is the distribution of those features and their relationships to each other.

Consequently, I need first a map of the surface features of the region, from which I can gain knowledge of the amounts of each feature and the distribution and juxtaposition of all significant features taken as a system. When completed, I will have a current inventory of the region's resources and a basis by which to monitor changes in the distribution of each category in the future.

In addition to the distribution of each resource category, there are items of detailed information about many of them which will also be required. Some can be inferred from the graphic data; other information will require field inspection. These include:

1. The amounts and quality of wildlife habitats in terms of particular wildlife species.

2. The distribution and quality of surface water.

3. The distribution of roads, trails, and other human works such as ranches, fences, mines, timber cuts, etc.

4. Urban and industrial site locations, size, and type.

5. The distribution of agricultural practices and crop types.

6. Critical wildlife areas such as winter ranges, breeding grounds, watering sites, etc.

Given these requirements what choices are available as methods for obtaining the data? First, it is obvious that some of these data will require physical on site inspection and that other data can be collected remotely. If we establish a hierarchical approach, we might first want to locate, identify, and map the larger features and major classes over the whole area. For this purpose, LANDSAT satellite data would be a good choice, since it is inexpensive and readily available. About the only real alternative to accomplishment of such mapping in a reasonable time period would be high altitude aircraft imagery, at considerably greater cost.

Now I would like to digress briefly to address the LANDSAT capability and to illustrate some reasons for the satellite's advantages and disadvantages in a resource management context.

Ecological applications of LANDSAT data have been broad and varied since the first LANDSAT vehicle was launched in 1972. Some have been successful, many have not. But, perhaps the largest category of results from attempted applications would be characterized as partially successful. This result, common in ecological research due to the many uncontrollable variables typically considered, is frequently intensified when remote sensing technology is studied, because of the wide array of different data and processing combinations available to the investigator. For example, in a natural landscape, plant phenology has a large and frequently unpredictable effect on the degree of success experienced in classifying natural vegetation by remote sensing methods. The investigator must always consider the possibility that his results would have been significantly different if the remote sensing data had been acquired at a different time.

Because of its wide area coverage capability (100 x 100 nautical miles; 185.2 Km^2), LANDSAT data is obviously superb for regional coverage. However, the important question is, what kind of information does the data contain? Obviously, the information content of the LANDSAT data is a far more important attribute than merely the coverage area. To date, the LANDSAT sensors have generally not been able to provide reliable estimates of detailed ecological parameters such as species composition, productivity, foliar cover, etc. Although these limitations have frequently been attributed to the satellite's coarse resolution (approximately 80 m), there are several other factors, including atmospheric transmission and scattering of radiation, which combine to limit the system.

It might be well at this point to interject a few cautions in regard to the spatial resolution of LANDSAT data from the standpoint of operational dependability. Nominal system resolution of the LANDSAT multispectral scanner is about 79 m (260 feet). This means that the smallest resolvable ground target is about 260 feet square (0.6 ha) in size. But, this figure is based on an average contrast ratio and in optical systems greater contrast generally means greater resolution so it is with LANDSAT. I have personally processed LANDSAT data which clearly demonstrated a resolution of about 60 feet (18.2 m) with a high contrast target, but this was an exception to the rule.

If you square the nominal resolution of 260 feet you will come up with an area resolution of approximately 1.1 acres, and this is indeed the size ground area represented by each single element in a LANDSAT picture.

But, because of the possibility of mixed classes in a single resolution element, it is not advisable to depend on 1.1 acre resolution. Theoretically, any single resolution element should be surrounded on all sides by elements of the same class in order to minimize the probability of misclassification due to the mixture problem. The resulting group of nine resolution elements will amount to a ground area of about 10 acres (4.05 ha). Therefore, although one might occasionally do better, I consider it risky to depend on LANDSAT data for resolution smaller than 10 acres.

Now that I have criticized LANDSAT, I would like to suggest some potentials which may be unrecognized. I believe there is a strong possibility that the LANDSAT data actually contains more ecological information than we have realized. Could it be that we have simply been asking the wrong questions? Anyone who has spent much time in computer processing of LANDSAT data knows that there frequently will appear anomalous surface features in the classified scene. Usually these features are ignored and eliminated from the final map because they cannot be explained. Classes are broken out which cannot be explained by available ground truth data, particularly when applying an unsupervised automatic data classification computer program. These anomalies must have a physical/biological basis, for they can only represent differences in reflected and transmitted radiation. Therefore, rather than discard them as noise or permanent anomalies, perhaps these unidentified classes would be better be treated as clues to ecological phenomena which should be studied. They should be considered answers for which we must find the questions. It seems quite reasonable to postulate that some such questions may have more ecological meaning than some of the traditional questions we are accustomed to asking.

To date, LANDSAT data have been demonstrated capable of producing land cover classification maps in a variety of broad vegetation and land use classes. Most studies on the subject are difficult to compare because, among other reasons, the classifications were different. No classification system has been devised which is equally suitable to all applications, even within one discipline such as wildlife management. The classes into which LANDSAT data are organized depend in large part on the use of the data, and within limits, they may be selected to fit the planned applications.

Presently, it is difficult to predict exactly how many and what classes any given LANDSAT data set will provide. There are, of course, certain class distinctions which can obviously be made, such as forest or nonforest, land and water, etc. But beyond this level it is very much a matter of experimentation. Much depends on the particular data set that is selected because of phenological variations which result in more or less scene contrast in various wavelength bands.

Regardless of the classes selected, ground reference data, or ground "truth" is prerequisite to systematic data processing. Therefore, adequate provisions should be made for the acquisition of ground truth information for use in training the computer if digital classification is planned, or to train the interpreter if a manual approach is taken. I believe the best approach is to make an estimate, based on past experience, as to what classes may be distinguishable, and design the ground truth data collection effort around that estimate. In estimating, it is probably better to err on the optimistic side, since return trips to the field are expensive. It is also important that persons very familiar with the surface features to be classified participate in the actual computer classification process. In wildlife and other ecological applications, these individuals should be trained ecologists, with considerable field experience in the area under study.

In effect, the participation of a trained ecologist in the classification process amounts to the injection of ancillary data to the classification process, without which the computer is severely hampered. Likewise, in the manual interpretation process a photo analyst unfamiliar with the area, depending entirely on small training or reference sites to make the correlation between the data and the real world, is at a significant disadvantage.

For purposes of classifying into the broad categories for which LANDSAT data are normally used, the ground truth data can be qualitative and comparatively general in most operational cases. In research applications, the ground truth requirement will be more stringent. The field information required for general vegetation classification may vary from knowledge only of the single dominant species, as for a homogeneous forest cover, to statistical estimation of species composition for more complex types.

For computer classification, each training site should be large enough in area to produce representative statistical description of the class's spectral characteristics. Although many factors influence this requirement, 40 acres (16 ha) would probably be adequate for most classes. Another important requirement in training site selection is that each site be positively identifiable in the LANDSAT image, for selection of the correct boundaries to be used for training. Although this requirement may seem trivial, it is not, because small areas can easily be confused, especially in a complex LANDSAT scene.

The end product of LANDSAT digital classification will typically be a set of maps, and digital classification tapes. The tapes are of particular value because they can be used to produce additional maps at the scales, and portraying the particular classifications, which are most useful for field management purposes.

Thus far, we have produced regional classification maps displaying major vegetation types, land uses, and other categories of land cover information which could not reasonably have been obtained by ground methods. On the other hand, the LANDSAT maps could not have been produced without the use of ground truth information. Therefore, we have an integration of the two categories of technology, each dependent on the other.

The next step in our regional environmental assessment would be to obtain more detailed information about certain features and areas of interest, than we uncovered either by ground or LANDSAT investigation in our regional classification effort. From a wildlife standpoint, it is frequently necessary to have more specific information on the vegetative community structure and its habitat value for various wildlife species, than we are able to obtain from LANDSAT data. Therefore, the next step would probably be to devise a sampling scheme, based on the distribution of major vegetative types as disclosed in the LANDSAT maps, for estimating such parameters as species composition, vegetative cover or density, and other factors.

Based on the distribution of the major types we can plan aerial photographic missions to acquire color infrared imagery of selected sites within our region. The criteria for selecting these detailed sampling sites would be determined according to projected land uses and resource management objectives. In our case, we might select for study those sites which have been nominated for mineral leasing, or have been proposed for development of any type. Other criteria, important from a wildlife standpoint, involve the concept of "key" areas. Although this term would be subject to definition for any particular situation, typical criteria might include consideration of endangered species habitats, winter ranges, breeding or mating areas, or waterfowl nesting habitat.

With color-infrared (CIR) aircraft imagery of medium scale, combined with the necessary ground checking, we can obtain detailed information about specific characteristics and any limiting factors which occur on these critical areas. For example, with LANDSAT data we may only be able to distinguish that a particular area is a mountain shrub community. On a regional scale, such a general level of information detail may be sufficient, but that level is not sufficient for management based on the carrying capacity of the area for particular wildlife species. Therefore, we would use the aircraft imagery to further break down the mountain shrub community into specific components, and shrub species, based on their value for particular wildlife species. Likewise, for waterfowl nesting habitat the very high infrared reflectance of a marsh may result in spectral characteristics very similar to those of an irrigated hay meadow. To distinguish one from the other, and then to estimate relative value as nesting cover, the aerial CIR together with ground investigations would probably be required.

The approach to obtaining ground truth information to support color infrared imagery investigations is not unlike that required for LANDSAT. The procedure is to select certain areas which are believed representative of the classes or subclasses of interest, estimate the parameters of interest by conventional methods, and then project those parameters to larger areas by analysis of the color infrared imagery. In the example of the mountain shrub community, if our interest is merely to separate shrub stands by species or groups of species, we need only visit representative sites, identify the species of interest, and perhaps visually estimate the relative composition. However, if we are interested in a more precise estimate of wildlife value, we may want to statistically estimate production, current annual growth of selected browse species, or other parameters. Whether the distribution of such detailed parameters can be accurately inferred in color infrared imagery, based on limited ground sampling, has been conclusively demonstrated only on small areas. The Office of Biological Services now has a research contract in progress to investigate the possible extension of these types of data by manual and semi-automatic processing of color infrared imagery.

I have discussed the two broadest categories of remote sensing applications to resource management. Regional land cover classification with LANDSAT data, and detailed subsampling with aircraft imagery. There are other types of more specialized information related to wildlife management, which also requires both aerial and ground methods, as follows:

- Airborne thermal infrared scanners can be used to map thermal contours in water bodies, which are of interest regarding thermal pollution of fishery boundaries based on water temperature. But, ground temperature sampling will be necessary for accurate calibration.

- Airborne scanners or cameras may be used to locate raptor habitat, but ground inspection will probably be necessary for positive species identification.

- Remote sensors can pinpoint sources and distribution of some types of water pollution, but water quality can only be determined by ground sampling.

In general, remote sensors are superb at detecting and recording the distribution of various phenomena, thus alerting one to the fact of each phenomenon's existence and the need for closer, ground, inspection.

What I have discussed so far involves the extraction of qualitative information about the nature of surface features from remote sensing data, and this type of activity has been the essence of remote sensing research for many years. However, there are two additional aspects which must be considered when applying the data in an operational mode. These aspects involve mapping precision and data storage.

In order to make use of the information obtained from remote sensing data, it must be displayed or stored in a format which is usable and accessible by field management personnel. The obvious format to use is a map, and this type of graphic portrayal is ultimately what will be needed for resource management purposes. However, map storage representing large quantities of information is cumbersome at best. Therefore, digitizing the map-based information and subsequent computer storage would seem to be inevitable in a fully operational system. I shall now briefly discuss both mapping precision, and computer information storage.

The science and technologies of cartography and photogrammetry were around long before the upsurge of current interest in modern remote sensing. Consequently, little attention has been paid to the cartographic aspect of the problem. With a few notable exceptions, most remote sensing research has been directed at the production of qualitative information about the nature of surface features or at various mensuration techniques required to spatially quantify the information derived, rather than at mapping them with accuracy.

The mapping process followed in any particular application depends on the accuracy required in the final map products. For most resource management applications, extremely high precision, such as one would obtain through the use of a first order stereoplotter, is probably not required. Much useful information has been obtained simply by laying the transparent photographic image directly over a base map of the same scale, completely ignoring the geometric error which is inherent in any aerial camera system. However, this is a poor solution at best.

The next step up in accuracy is presented by the several different types of devices which optically superimpose the photographic image on a base map of the same or different scale. Such devices do provide better mapping precision than simply overlaying the image directly on the map, although they are only capable of limited error correction based on visual correlation of the photographic image features with corresponding features.

The next step in increasing mapping precision involves the use of one of several different types of stereoplotters. These machines require a stereo image pair to create a stereo model which simulates the perspective of the camera lens at the time the images were obtained. These machines mechanically or electronically correct for most types of geometric error by referencing the entire model system against known ground points, of which the exact locations and elevations are known. Analytical photogrammetric methods can be used, over areas where control points are sparse, to project the reference framework through multiple image sets, from control points located adjacent to the bridged area.

As mentioned previously, the primary determinant in selecting which mapping approach should be followed in any given application depends on the ultimate use of the map data. It would be wasteful to follow the stereo plotting approach, which is extremely time consuming and labor intensive, for most resource management applications, excepting those involving changes in land ownership or related legal documentation. Likewise, the rougher approximations would not be suitable where land unit boundaries were under investigation. In short, there is no easy prescription for a mapping procedure; each case depends upon its own particular set of circumstances.

Computer-based spatial data storage systems, although expensive, complex, and as yet imperfect in many respects, are inevitable tools of the future resource manager. Likewise, I believe remote sensors will be the primary spatial information sources on which these systems will depend, particularly for keeping the system current. Therefore, the integration of the two technologies is basic to a functional, operational land resource inventory and monitoring capability.

Others, more qualified than I, have spoken or will address this symposium on the technical aspects of computer information systems. I would like only to point out a few basic considerations which I think are important in the development of such systems for natural resource management application.

First, I cannot foresee the day when human resource managers will not be needed; humans like to use maps. Virtually any type of information which has a geographic component can be represented more vividly and interpreted more rapidly by humans from a graphic format than from a tabular one. Therefore, in designing a computer information system, we should design the primary input and output modes around map reading and writing. The technology of image processing is rapidly developing, and within the next few years I expect that fully automatic digiting, encoding, and computer storage of map-based data will be a reality, regardless of the source of map data.

A map-based computer information storage system also provides a common, geographically referenced framework on which to organize field data, whether obtained by ground or aerial methods. This advantage alone will constitute a major improvement over current manual data storage, because it necessarily imposes a systematic approach to the data acquisition, storage, and application processes.

In summary, I reemphasize several points:

1. The importance of insuring the need for and utility of any field data that is gathered cannot be overstated. Whether acquired by ground or aerial means, the purpose for which the data is obtained must be kept in the forefront of data acquisition planning and execution.

2. Resource managers must become aware and operationally familiar with all the tools at their disposal, including remote sensing and other new technologies, so that the right tool is used for each data requirement.

3. Remote sensing and conventional methods need not be forcefully integrated. As I have shown, each depends on the other to a greater or lesser extent, depending on the application. The important thing to consider is whether the tools used are up to the job. Remote sensing cannot provide all the needed information and neither can ground methods. Together, however, they constitute a broad capability for intensive resource management which is heretofore unequalled and which, in the future, will be indispensable.

LITERATURE CITED

Giles, R.H. (ed.). 1969. Wildlife Management Techniques. The Wildlife Society, Washington, D.C. 632 pp.

Moyer, R.H. 1950. Some uses of aerial photography in connection with the production and marketing programs of the U.S. Department of Agriculture. Photogramm. Eng. 16:305-307.

A REVIEW OF EXISTING GEOGRAPHICAL INFORMATION SYSTEMS AND SOME RECOMMENDATIONS FOR FUTURE SYSTEMS

J. Curtis Wilcott
Office of Biological Services
U.S. Fish and Wildlife Service
Rm. 206, Federal Building
Ft. Collins, Colorado 80521

William A. Gates
Institute for Environmental Studies
University of Wisconsin-Madison
Madison, Wisconsin 53706

INTRODUCTION

Geographical information systems hold the promise of providing planners and land managers with rapid access to many reels of tape and/or several disk packs of data and the ability to manipulate and display it in a variety of ways. Here are a representative set of questions that could be handled by a good system (the reader is asked to substitute his own names for our abbreviations A, Q, K, etc.):

1) Given a proposed land use A and related site criteria Q, which sites in the study area are most suitable? (This is similar to the manual overlay technique of suitability mapping as popularized by McHarg.)

2) How many miles of second-order streams are there in Senate District 10?

3) Display the Dane County soils map at a scale of 1:24,000 along with the county road network.

4) List the types of wildlife habitat in study area K and indicate total number of acres for each.

5) Display all areas in Region 6 that have vegetation type B and are at elevations greater than 5,000 feet (1,524 km).

6) Which sites can be viewed from point E?

7) What areas in the study area are within 2 miles (3.2 km) of a water sampling station?

8) How far downstream is point M from point N?

Few existing systems can handle more than one or two of the above types of questions. Part of the reason is the form in which the data has been organized and stored in the data base, part is due to the high cost of performing the task because of poor software design and implementation and, lastly, the ability of computer systems to perform these tasks has not been perceived and subsequently demanded by planners and land managers.

Before attempting a review of the existing software for handling geographical data, we need to provide some background information about modes of computer operation and methods of encoding and processing geographical data. A bibliography has also been provided, with the citations arranged according to subject areas.

MODES OF COMPUTER OPERATION

BATCH MODE

This has been the traditional way of communicating with a computer program--by submitting a deck of punched cards that contain the user's request. The sequence of cards and the position of the numbers (commands) on the cards must correspond exactly to what the program expects. If not, when the program encounters the first error, it "dies" with some (usually) obscure error message. Only after repeated corrections and resubmissions can one get the desired output, a process that can take hours or days! Also, input/output clerks can lose the printed output, lose the input deck, or drop (shuffle) the input deck before or after a run.

The batch mode is the easiest for the writer(s) of the software and the most demanding on the software user. The programmer usually assumes that the system will only be used by himself (or by other experienced programmers) and pays scant attention to making the software "user oriented." There is a need for a user's manual for software of any complexity. This implies a high learning threshold for the user to become familiar with the software. Planners and land managers are effectively eliminated from "hands on" access to the data. They must communicate their needs to a programmer. The situation usually leads to non-use of the system by the planner!

INTERACTIVE MODE

In the interactive mode the user communicates with the program via a teletypewriter, a CRT terminal (text only), or a graphics terminal (text and line drawn images). The interactive program processes each input line as the user enters it. The interactive environment demands that the input be free format and that complete error detection and recovery are provided. (It is inexcusable for the user to be able to terminate an interactive program by providing the wrong data or command!) The program can also "prompt" the naive user by telling him what information is required or what commands are available at any point in the session.

These features allow for considerably reduced dependence on a user's manual. The user can let the software teach him how to use it. The time required to correctly specify all of the parameters for some complex query or manipulation of the data is reduced from hours in the batch mode to a matter of minutes in the interactive mode. The major disadvantage is the much higher level of programming skills that are required to write interactive software that has all of the above features. But if one really wants planners and land managers to use the system themselves, the interactive mode is the only choice.

DATA ENCODING AND COMPUTER PROCESSING TECHNIQUES

The kinds of information that are depicted on most maps or orthophotos are quite varied. They may be characterized as:

1) point data (elevation bench marks, sampling points, etc.);

2) network data (streams, roads, etc.);

3) isarithmic data (topographic maps, isobar weather maps, etc.); and

4) closed area data (soils, vegetation, land use, etc.).

There are several methods of encoding this map information for computer processing, including manual grid cell, manual digitizing, automatic line following, and raster scanning. Only the first two methods will be discussed here. Interested readers are referred to Tomlinson (1972, under Geographical Data Handling) for further information.

MANUAL GRID CELL

Geographical data may be extracted from the source document by placing a regular grid pattern (cells need not be square) over the document and recording what features occur in each cell (Figure 1). This has been the most widely used method in existing systems because the hardware and software requirements are minimal and computer algorithms are simple. Additionally, the level of skill required is within the capability of an individual or a small planning group to do without seeking technical support beyond that of a moderately competent programmer. This technique necessarily loses some of the spatial detail in the source document, but it allows one to use a standard line printer or teletype as the output device, with one or more print positions to represent each grid cell. Geographical data in grid cell form also facilitates the combining of various kinds of data with variable weighting functions to arrive at a "value" or suitability map for planning purposes (Figure 2). Grid cell data is the only form that may be readily subjected to standard statistical analysis.

The disadvantages of this method are the loss of spatial resolution and the fact that the output does not "look" like a map. (It is possible to produce line-drawn output from grid cell data, but the resulting implied spatial resolution is very misleading!) The grid cell technique has been used in situations where fixed spatial resolution (size of the grid cell in acres or hectares) and the production of suitability maps in line printer "overprint" form are acceptable limitations.

MANUAL DIGITIZING

In manual digitizing, XY coordinate pairs are recorded for one or more points as needed to describe each spatial feature. Resolution is usually 0.001 as measured from some arbitrary origin on the digitizing table. This origin is typically set in the lower left corner of the source document so that all coordinate values are positive. Line shapes can be recorded with a high degree of accuracy and the output devices can be either an XY plotter or a graphics terminal. Considerable effort is required in editing the data, because of human digitizing errors and occasional hardware failure.

There are two ways of digitizing documents with closed area data: line segment or polygon. In the line segment approach, each unit of data is the set of XY coordinate pairs that record the line snape between two node points (Figure 3). In the polygon approach, the basic unit of data is the set of XY coordinate pairs that completely enclose a single closed area (Figure 4).

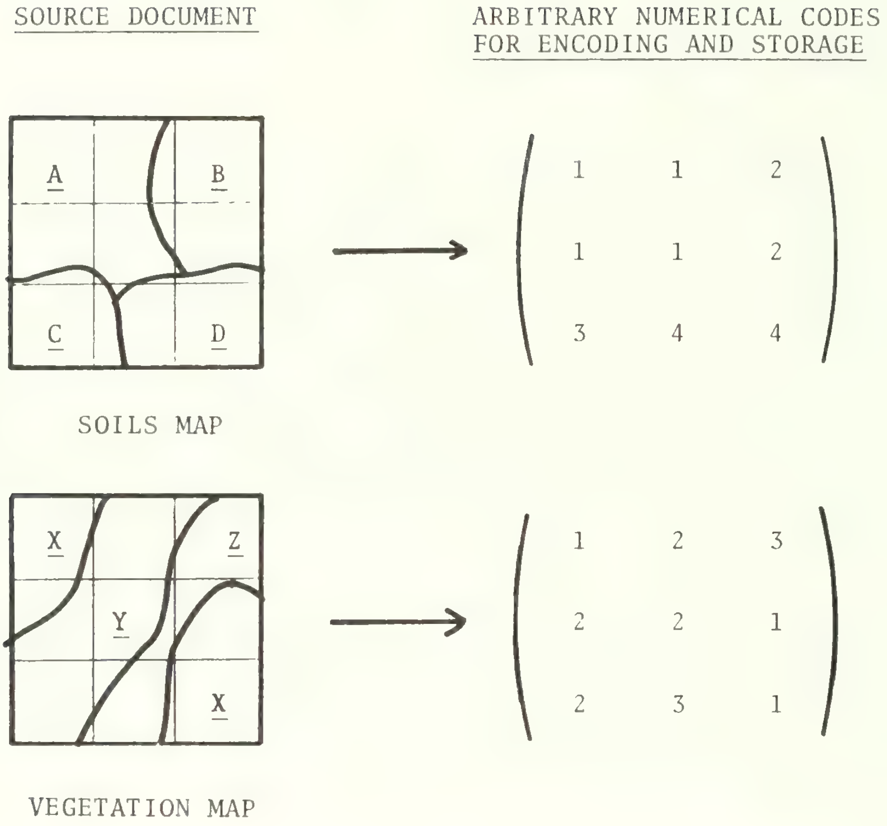


Figure 1. Example manual grid cell encoding.

	DATA TYPE	ARBITRARY CODE	VALUE[a] (QUALITATIVE)	VALUE[a] (QUANTITATIVE)
SOILS	A	1	high	9
	B	2	low	1
	C	3	medium	5
	D	4	low	1
VEG	X	1	medium	5
	Y	2	high	9
	Z	3	low	1

[a] assigned values are relative to some particular land use

Assuming that vegetation is twice as important a criteria as soils, cell suitability scores would be given by:

SUITABILITY = 1*(SOILS VALUE) + 2*(VEGETATION VALUE)

For the whole map (refer to Figure 1),

$$\text{SUITABILITY MATRIX} = 1*\begin{vmatrix} 9 & 9 & 1 \\ 9 & 9 & 1 \\ 5 & 1 & 1 \end{vmatrix} + 2*\begin{vmatrix} 5 & 9 & 1 \\ 9 & 9 & 5 \\ 9 & 1 & 5 \end{vmatrix}$$

$$\text{"} \qquad \text{"} = \begin{vmatrix} 19 & 27 & 3 \\ 27 & 27 & 11 \\ 23 & 3 & 11 \end{vmatrix}$$

A grey scale (overprinted) representation would be:

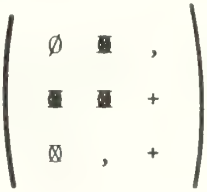
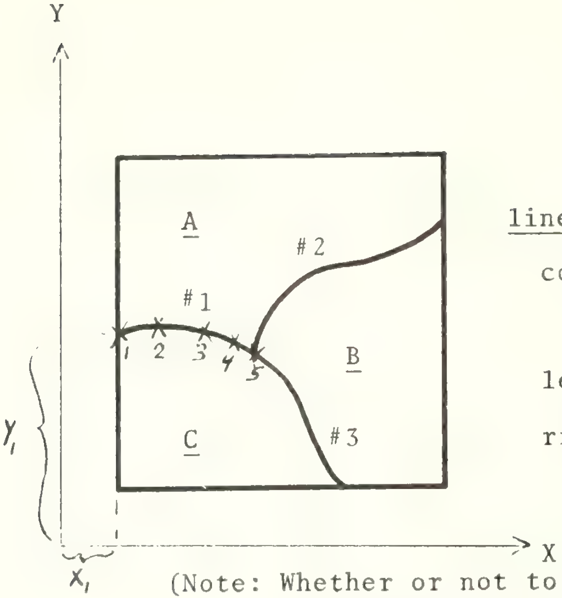


Figure 2. Example grid cell manipulation.



line segment #1

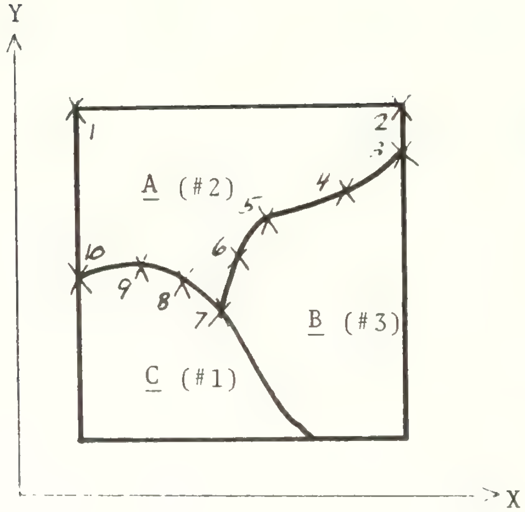
coordinates: X_1Y_1, X_2Y_2, X_3Y_3, X_4Y_4, X_5Y_5

left attribute: A

right attribute: C

(Note: Whether or not to digitize the map edges is a system-wide decision)

Figure 3. Example manual digitizing (line segment).



polygon #2

coordinates: X_1Y_1, X_2Y_2, X_3Y_3, X_4Y_4, X_5Y_5, X_6Y_6, X_7Y_7, X_8Y_8, X_9Y_9, $X_{10}Y_{10}$, X_1Y_1

contained attribute: A

Figure 4. Example manual digitizing (polygon).

Polygon encoding is wasteful of storage space since each segment of a closed area boundary will be recorded twice (but in opposite directions), as a boundary segment for each of the two areas that it separates. Line segment encoding requires more processing time to link the line segments that form a closed area. Figure 5 shows in Venn diagram form how two digitized line maps could be combined (overlaid).

The disadvantages of the manual digitizing method are the need for specialized hardware (digitizing table and plotter), the increased computer processing costs to produce line intersection overlays, and the fact that suitability maps cannot be generated directly. However, when the original resolution (line shape and location) of the source document must be retained for combining the data with documents of differing scales and differing areas of coverage, the manual digitizing technique is the best approach. This also produces a map output that looks like a map.

EXISTING GEOGRAPHICAL INFORMATION SYSTEMS

There is a great deal of software for the handling of geographical data. Table 1 contains a list of some of the well-known systems. State of the art reviews of geographical information systems may also be found in Tomlinson (1972) and Alsberg et al. (1973). Since our review is based upon published reports, our descriptions of them may be somewhat dated. Rather than discussing any particular system in detail, an attempt will be made to categorize them according to their two most telling characteristics: whether the system is batch or interactive and whether the data format is grid cell or digitized line (polygon). An additional criteria that could be used is whether the system possesses meaningful data management facilities.

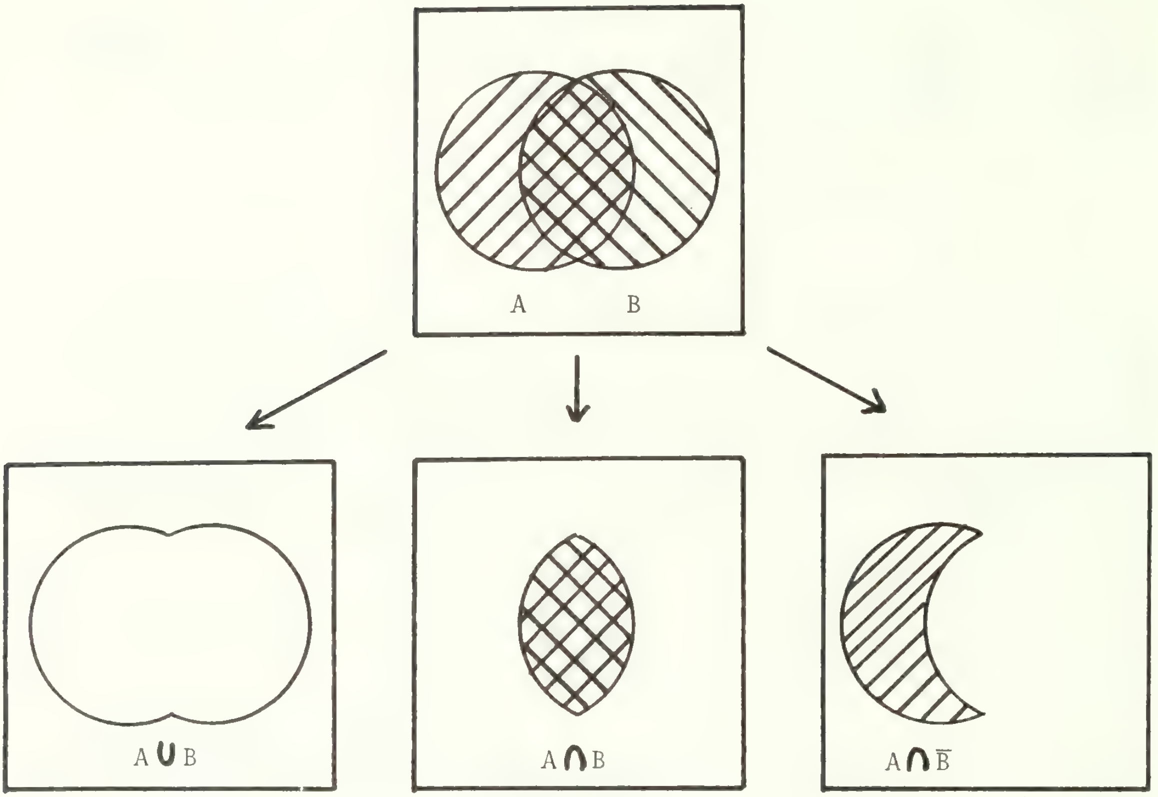
Most information systems have the following steps for processing data: (1) data encoding and editing; (2) insertion into the data base; (3) retrieval, manipulation, and display; and (4) updating or deletion.

Some (or all) of these steps may be batch or interactive, since each step is often accomplished with a separate program. A truly interactive system would have all steps (with the possible exception of step 1) in a single, interactive program. However, each system in Table 1 has been classified as batch or interactive, depending on the mode used for step 3: retrieval, manipulation, and display.

Some of the batch systems have been or probably will be converted to the interactive mode. However, the authors believe that systems that were conceived and implemented as batch systems cannot effectively be converted to interactive systems. The computational techniques and data structures that were suitable for batch software result in excessive costs and slow response in an interactive mode.

BATCH/GRID CELL

This combination has proven to be the most widespread because the grid cell technique is easily understood and applied to a particular study area. The computer processing of grid cell data (manipulating rectangular arrays of numbers) is easy to program and inexpensive to run. Systems in Table 1 that have these characteristics (in approximate chronological order of development) are GRID/Honey Hill, LUNR, REMAP/I-57, MLMIS, ORRMIS, and MAGI. Only the last



UNION (A or B) INTERSECTION (A and B) INTERSECTION (A not B)

Figure 5. Venn diagram of possible line intersection combinations of closed areas from two different data maps.

Table 1. Existing Geographical Information Systems

Name	Publication date	Author	Data format	Mode
AUTOMAP	1974	MITRE Corp.	line segment	batch
CGIS	1974	IBM	raster	batch
COMLUP	1972	Allen	line segment	batch
GIDS	1972	Parker et al.	polygon	interactive
GRASP	1974	Gates	grid cell	interactive
GRID	1971	Sinton et al.	grid cell	batch
IMAGE	1974	Boyle et al.	line segment	interactive
LUNR	1970	Belcher et al.	grid cell	batch
MAGI	1974	ESRI Inc.	grid cell	batch
MAP/MODEL	1968	Arms	polygon	batch
MLMIS	1974	Borchert	grid cell	batch
NARIS	1972	Alsberg et al.	parcel	interactive
NRIS	1973	Raytheon	line segment	batch
ORRMIS	1973	Durfee et al.	raster & grid	batch
PIOS	1970	ESRI Inc.	polygon	batch
PLUS	1974	Goodchild	polygon	batch
REMAP/I-57	1971	Niemann et al.	grid cell	batch

three systems are being used in day-to-day planning environments. ORRMIS is noteworthy because of the quality and variety of graphical outputs and because it can relate Landsat remote imagery (pixel) data to their more conventionally obtained grid cell data.

BATCH/DIGITIZED LINE

As with the grid cell technique, the earliest attempts at digitized line systems were batch. Referring to Table 1, one sees that MAP/MODEL, PIOS, COMLUP, PLUS, and NRIS are the best known examples of this type. All but COMLUP and PLUS combine maps by the intersection of line segments or polygons. For maps with large amounts of data (e.g., most soils maps), this has proven to be an expensive process. COMLUP and PLUS attempt to avoid this cost by converting the digitized line data to grid cell form (with subsequent loss of resolution) and then overlaying maps in the grid cell form.

INTERACTIVE/GRID CELL

The only example of an interactive grid cell system of which the authors are aware is GRASP (Gates et al. 1974, McCown et al. 1975). GRASP was designed for the interactive input and editing of the grid cell data, as well as for manipulating and displaying it.

INTERACTIVE/DIGITIZED LINE

The best examples of this type of system are GIDS and IMAGE. GIDS stores, manipulates, and displays the data completely in polygon form. IMAGE is a minicomputer system that evolved in a hydrological/cartographic environment.

OTHER SYSTEMS

Some of the systems in Table 1 do not conveniently fit the above categorization scheme. AUTOMAP is a batch system that is specifically designed to process digitized stream network data. Most of the output is in tabular rather than map form. CGIS is the very extensive Canadian system that first raster scans the source document and then converts to polygon form for permanent storage, manipulation, and display. Map scales range from 1:50,000 to 1:250,000, with the bulk of the data at the 1:250,000 scale. It is a batch system that currently emphasizes report-generating features rather than map-generating features.

NARIS is unique in that it uses property parcels as the basic geographical unit of data collection. The technique is similar to the grid cell approach because one records those features which occur in each arbitrarily shaped (but fixed) parcel. Output can be in tabular form, based on the unique parcel identifiers, or in map form using the digitized parcel boundaries to delineate areas. NARIS also possesses one of the more "user oriented" languages of the systems that were reviewed.

OBSERVATIONS

There has obviously been a great deal of activity in the area of geo-information systems. The list of systems (Table 1) is undoubtedly incomplete. It is also clear that there has been great duplication of effort. Some of the duplication is due to lack of awareness of what other groups are doing. Some is due to the conviction that one's own needs are sufficiently different that adapting system X will not do. Lastly, some duplication is due to the well-known not invented here (NIH) syndrome.

Most of the existing systems evolved in environments that were limited in programming staff and/or hardware facilities. Most employ rather unsophisticated programming techniques (primitive data structures and a batch transaction orientation), partly because the volume of data was relatively small and partly because they were not really intended to be directly used by planners and land managers. Also most systems lack data management facilities so that access and updating individual records can only be accomplished by disturbing the entire data base. If one is seriously considering maintaining massive amounts of geographical data that are to be directly used by planners and land managers, none of the existing systems will be adequate.

RECOMMENDED FEATURES FOR FUTURE SYSTEMS

INTERACTIVE

The system must be designed as interactive to allow for "hands on" use by planners and land managers with a minimum of training. This also permits geographically dispersed users to access one or more central computer facilities with minimal hardware requirements (teletype and modem). The system should have two levels of "prompting" messages. Naive users can be prompted all the time and more experienced users can turn off these messages in processes that they know well. As much as possible, users should be able to reference data in terms (names) that are familiar to them, rather than by arbitrary numerical codes.

QUERY AND MANIPULATION LANGUAGE

There should be a simple command language that can be easily expanded as the system evolves. For information retrieval, the query language should allow users to learn what data is in the base in much the same manner that a subject/author/title catalog serves a library user. Maps should be able to be retrieved by a key work search (title, scale, vintage, etc.) or by specifying geographical coordinates (latitude/longitude, Universal Transverse Mercator, etc.).

After a user has identified data of interest, the manipulation part of the language provides him with the tools to do something with that data. This part of the language will be very application oriented and the vocabulary and grammar will depend on the planning environment in which the system is to operate.

HYBRID

Data in both grid cell and digitized line forms should be handled by the system. The optimal scheme would have most of the basic data in digitized line form (maximum resolution and minimum storage requirements) so that maps with different scales and/or areas of coverage can be related (overlaid). For generating suitability maps, the digitized line data could be converted to a user-specified cell size. Line intersection maps could also be produced, but at higher cost.

REPORT GENERATION

Producing a map output is not the only requirement. The system should have statistical analysis and report generation functions in order to be a true "information system."

DATA BASE MANAGEMENT

Maintaining large quantities of data in an interactive system demands that most of the standard data base management techniques be employed in system design:

(1) a single file on secondary storage so that different data sets can readily be related to one another;

(2) some measure of file security (read/write keys, user passwords, etc.);

(3) a data base administrator who will be responsible for data integrity and accuracy and for determining the needs for additional software development;

(4) as much data/program independence as possible; and

(5) an archiving facility for interactively moving infrequently used data between secondary storage (disk or drum) and long term storage (tape).

USER FEEDBACK

The system should provide the user with meaningful feedback as it carries out a request. One example would be the cost of doing each step in a key work search of the data base. The user would learn which parts of his query are easy (cheap) and which parts are difficult (costly). He could then learn how to better specify his queries.

CONCLUSIONS

There are some specific computer science techniques that the authors feel are essential to effectively implement the above recommendations:

(1) formal language definition and a language processor (scanner, parser, semantics routine);

(2) dynamic storage allocation (core memory and disk); and

(3) advanced data structures (hashing, threaded binary search trees, list processing, etc.).

As we have stated earlier, these techniques represent at least an order of magnitude increase in the level of programming skills over that evidenced in most existing systems. Unless a programmer has a recent computer science degree from a major university, he probably does not possess these skills and acquiring them will involve considerable self-teaching or formal academic training. Even this individual may lack appreciation of what "large amounts of data" means.

A second area of concern is the "institutional" problem of gaining acceptance by the planner or land manager who is to use the system. Unless the user is actively involved in system development, he will probably resist its introduction and refuse to use it. Two ways in which the user can be a part of system development is the identification of the kinds of data that he needs and in the specification of a query and manipulation language that is suitable and understandable. Both of these processes (language design and data identification) can and should precede actual system implementation.

BIBLIOGRAPHY

DATA STRUCTURES AND FILE ORGANIZATION

Bell, J.R., and C.H. Kaman, 1970. The linear quotient hash code. Communications Assoc. For Computer Machinery 13:675-677.

Knuth, D.E., 1968. The Art of Computer Programming, Vol. 1: Fundamental Algorithms. Addison-Wesley, Massachusetts. 634 pp.

Knuth, D.E., 1973. The Art of Computer Programming, Vol 3: Sorting and Searching. Addison-Wesley. Massachusetts. 722 pp.

Mauer, W.D., and T.C. Lewis, 1975. Hash table methods. Computing Surveys 7:5-19.

Price, C.E., 1971. Table lookup techniques, Computing Surveys 3:49-65.

Severance, D.G., 1974. Identifier search mechanisms: A survey and generalized model. Computing Surveys 6:175-194.

Sussenguth, E.H., Jr., 1963. Use of tree structures for processing files. Communications Assoc. for Computer Machinery 6:272-279.

DIGITIZED LINE PROCESSING

Aldred, B.K., 1973. Points in Polygon Algorithms. Report UKSC-0025, UK Scientific Centre, IBM, Neville Road, Peterlee, County Durham, England.

Auerbach Publishers, 1972. Auerbach on Digital Plotters and Image Digitizers. Princeton, New Jersey. 211 pp.

Freeman, H., 1974. Computer processing of line-drawn images. Computing Surveys 6:57-97.

Laboratory For Computer Graphics and Spatial Analysis, 1974. POLYVERT: A Program to Convert Geographic Base Files. Harvard University, Cambridge Massachusetts.

Newman, W.M., and R.F. Sproull, 1973. Principles of Interactive Computer Graphics, McGraw-Hill, New York. 607pp.

Pfalty, J., and A. Rosenfeld, 1967. Computer representations of planar regions by their skeletons. Communications Assoc. for Computer Machinery 10:119-123.

Sutherland, I., R.F. Sproull, and R.A. Schumacker, 1974. A characterization of ten hidden-surface algorithms. Computing Surveys 6:1-55.

EXISTING GEO-INFORMATION SYSTEMS

Allen, Neil, 1972. Computer Mapping for Land Use Planning (COMLUP), U.S. Forest Serv., R-4, Ogden, Utah.

Alsberg, P.A., W.D. McTeer, and S.A. Schuster, 1973. IRIS-NARIS: A Geographic Information System for Planners. Center for Advanced Computation, Univ. Illinois, Urbana. 36 pp.

Arms, Samuel, 1968. MAP/MODEL System: Technical Concepts and Program Descriptions. Columbia Region Assoc. Governments, Portland, Oregon. 35 pp.

Arms, Samuel, 1970. MAP/MODEL System: System Description and User's Guide. Univer. Oregon, Eugene. 59 pp.

Borchert, J.R., 1975. Perspective on Minnesota Land Use - 1974. Univ. Minnesota, Minneapolis. 56 pp.

Boyle, A.R., 1974. IMAGE: A Minicomputer Geographic Information System. Dept. of Electrical Engin., Univ. Saskatchewan, Saskatoon. 34 pp.

Center for Advanced Computation, 1972. IRIS: Illinois Resource Information System, Feasibility Study and Final Report. Univ. Illinois, Urbana. 204 pp.

Craven, C.W., Jr., M.M. McCarthy, R.J. Olsen, and C.R. Schuller, 1974. Regional Environmental Systems Analysis Program, Progress Report June 1973-June 1974. ORNL-NSF-EP-74. 131 pp.

Crowder, Robert, and Roger Swanson, 1970. User Manual for PLANMAP II. Office of Planning Services, Albany, New York. 25 pp.

Crowder, Robert, 1974. LUNR: Land Use and Natural Resource Inventory of New York State. Office of Planning Services, Albany, New York. 16 pp.

Dangermond, J., 1971. Polygon Information Overlay System. Comprehensive Planning Organization, San Diego, California.

Denenberg, S.A., C.C. Corbin, and P.A. Alsberg, 1972. NARIS: A Natural Resource Information System. Center for Advanced Computation, Univ. Illinois, Urbana. 15 pp.

Durfee, R.C., 1973. ORRMIS: Oak Ridge Regional Modeling Information System, Part 1. ORNL-NSF-EP-73, 103 pp.

Environment Canada, 1974. Canada Geographic Information System. Ottawa, K1A 0H3. 33 pp.

Gates, W.A., B.H. McCown, and K.S. Butler, 1974. Bit Plane Data Organization: Its use in Resource Data Systems. Inst. Environ. Studies, Univ. Wisconsin - Madison. 17 pp.

Goodchild, M.F., 1974. PLUS: Technical User's Guide. Dept. Geography, Univ. Western Ontario, London. 143 pp.

Maryland Department of State Planning, 1974. Maryland Automatic Geographic Information System. Baltimore, Maryland. 55 pp.

Mashburn, R.G., R.C. Durfee, and R.G. Edwards, 1976. REGRID: A Generalized Grid-to-Grid Transformation Procedure. ORNL/RUS-18. 71 pp.

McCarthy, C.V., 1974. The AUTOMAP System. MITRE Corporation, Bedford, Massachusetts. 127 pp.

McCown, B.H., K.S. Butler, and W.A. Gates, 1975. A Documentation of the Resource Information Package, GRASP, and Its Application to the Lake Superior Shorelands (draft). Inst. Environ. Studies, Univ. Wisconsin, Madison. 31 pp.

McHarg, Ian L., 1969. Design with Nature. Natural History Press, New York. 198 pp.

Miller, A.H., and B.J. Niemann, Jr., 1972. An Interstate Selection Process: The Application of Computer Technology to Highway Location Dynamics, Phase I. Dept. of Landscape Architecture, Univ. Wisconsin-Madison. 225 pp.

Murray, Timothy, 1971. Honey Hill: A Systems Analysis for Planning the Multiple Use of Controlled Water Areas, Volumes 1 and 2. Harvard Univ., Cambridge, Massachusetts. 725 pp.

Parker, J.L., 1971. Information Retrieval with Large-Scale Geographic Data Bases. Dept. Computer Sci., Univ. British Columbia, Vancouver. 39 pp.

Parker, J.L., 1973. File Structures and Access Methods for A Geographic Information Retrieval System. Dept. Computer Sci., Univ. British Columbia, Vancouver. 8 pp.

Raytheon Automatic, 1973. The Development of a Natural Resource Information System, Volumes 1 - 5. Wayland, Massachusetts. 542 pp.

Sinton, David, and Carl Steinitz, 1971. GRID Manual, Laboratory for Computer Graphics and Spatial Analysis, Harvard Univ., Cambridge, Massachusetts. 34 pp.

Taylor, L., and John Antenucci, 1974. Maryland Automated Geographic Information (MAGI) System. Maryland Dept. State Planning, Baltimore, Maryland.

Vanderbosh, Peter, 1972. An Interactive Picture Editor (A Subsystem of the Geographic Information Display System). Dept. Computer Sci., Univ. British Columbia, Vancouver.

Yan, J.Z., 1973. A Geographic Information and Display System (GIDS). Master of Science thesis, Dept. Computer Sci., Univ. British Columbia, Vancouver. 185 pp.

GEOGRAPHICAL DATA HANDLING

Davis, J.C., and M.J. McCullagh, (eds.), 1975. Display and Analysis of Spatial Data, Wiley, New York. 378 pp.

Tomlinson, R.F. (ed.), 1972. Geographical Data Handling, Volumes 1 and 2. Second Symposium on Geographical Inf. Systems, Intl. Geographical Union, Ottawa, Canada. 1,387 pp.

LANGUAGE PROCESSING

Aho, A.V., and S.C. Johnson, 1974. LR parsing. Computing Surv. 6:99-124.

Aho, A.V., and J.D. Ullman, 1973. The Theory of Parsing, Translation, and Compiling, Volumes 1 and 2. Prentice-Hall, New York.

Gries, David, 1971. Compiler Construction for Digital Computers. Wiley, New York. 493 pp.

MANAGEMENT INFORMATION SYSTEMS

Aron, J.D., 1969. Information Systems in Perspective. Computing Surv. 1:213-236.

Dodd, G.G., 1969. Elements of Data Management Systems. Computing Surv. 1:117-133.

Everest, G.C., 1974. Objectives of data base management. Pages 1 - 35 In J.T. Tou, ed. Information Systems (COINS IV). Plenum Press, New York.

Meadow, C.T., 1973. The Analysis of Information Systems. 2nd Edition, Wiley, New York. 301 pp.

Salton, Gerard, 1968. Automatic Information Organization and Retrieval. McGraw-Hill, New York. 514 pp.

Sterling, T.D., 1974. Guidelines for humanizing computerized information systems: a report from Stanley House. Communications Association for Computer Machinery 17:609-613.

THE BALANCED ECOGEOGRAPHICAL INFORMATION SYSTEM: A VEHICLE FOR DATA COLLECTION, SYSTEMATIZATION AND DISSEMINATION

H.P. Moyseenko, J.L. Woodall,
and S.A. Woodall
The Nature Conservancy
1800 North Kent Street
Arlington, Virginia 22209

Abstract: The Nature Conservancy, through its State Natural Heritage Programs, has developed a balanced information system for systematizing and managing data on certain biological species, habitats, communities, and geographical features. The system is referred to as "balanced" because it couples manual filing structures with computer mediated methods for inventorying, recording, mapping, and managing data. All information does not merit or lend itself to computerization. The task of organizing manual files to augment the computerized files has been a neglected aspect of many information systems. In the Nature Conservancy's Heritage Programs, data are collected in incremental layers. Extensive and comparable data are compiled and organized to facilitate comparative analysis. After information has been assimilated into standardized formats and files, a cyclical process is initiated to fill data gaps and to update and enrich the data base. The information theory facilitates the collection, management, and use of ecological data and is the hub of the Heritage process.

The data base is a collection of cross-referenceable manual and automated files. The manual files are designed to provide efficient access to lengthy and complex types of data. The computer programs comprise more than 12 modules which can be applied flexibly to many data processing needs. These programs have particular utility for collecting, managing, and displaying ecogeographical data. In addition to providing methods for data entry, update, and correction, the programs offer capabilities for highly selective search and retrieval, report production, and automated map generation. They permit record-by-record handling of data and accessing combinations of single and cross-referenced fixed and variable length records. The system has the potential to link up with other ecological data bases, thus making it possible for a wider spectrum of data to become centrally accessible. The information system serves not only as a storage and retrieval medium but also as a catalyst for the efficient flow of data from the field to the decisionmakers.

INTRODUCTION

The Nature Conservancy has long been a leading private organization dedicated to the preservation of ecological diversity. Its staff and members have been involved in many significant ecological inventory and preservation efforts. We have actively protected through outright acquisition over 1,500 ecologically significant tracts of land totaling more than 1 million acres (404,858 ha) in 48 states, Canada, the Virgin Islands, and the Caribbean. Much of this has been accomplished in cooperation with Federal, State, and local governments.

In order to protect the full array of natural ecological diversity, a great deal of information from different sources must be aggregated and systematized, so that we can identify the ecologically significant landspaces and allocate the resources necessary for their perpetuation. We feel that a comprehensive system capable of efficiently managing data on specific biological species, habitats, communities, and geophysical features is needed. The information system must not only serve as a multimedia storage and retrieval system, but act as a catalyst for the efficient flow of data from the field to the decisionmakers and to the scientific community. The inventory methodology and the balanced ecogeographical information system described in this paper is, in our view, an effective means for increasing our knowledge about significant ecological elements of natural diversity that occur throughout the United States; thorough knowledge about these elements is essential if we are to protect and maintain ecological diversity.

The purposes of this paper are twofold: to elucidate The Nature Conservancy's inventory approach and experiences with developing a balanced ecological information system; and to discuss how we solved the problems of data compilation and systematization so as to maximize our search, retrieval, and analytical capabilities.

INVENTORY AND CLASSIFICATION APPROACH

The Nature Conservancy has evolved a different approach to the problem of amassing, organizing, and utilizing ecological data. The keystone of The Nature Conservancy's inventory methodology lies in the process of organizing data on occurrences of elements of natural ecological diversity. The element occurrence approach is fully described by Jenkins (1976) and in an earlier presentation at this conference. At this writing, The Nature Conservancy has applied the element inventory approach in all or parts of 12 states through contracts with 9 State governments and the Tennessee Valley Authority. The data collection and management and the protection planning methodologies are part of what is known as State Natural Heritage Programs. Interested readers are referred to Moyseenko (1974) and Jenkins (1975) for further discussions on these programs.

We also organize data by site. The inventory methodology treats the necessity for a protection overview by incorporating managed ("protected") area data which complements the element occurrence approach. The overall system is thus structured to handle both managed area information and data on element occurrences. Each site is defined by legal boundaries, and is generally managed by a public or private body. Although legal boundaries of managed areas do not usually follow the boundaries of ecosystems, a species or biotic community can be protected only insofar as the land on which it exists is protected through various protection techniques. For this reason, in order to obtain an overview of the current adequacy with which examples of the elements of diversity are protected, data on managed areas and their component elements are collected. The question of using a variety of protection planning tools to preserve natural diversity is well discussed by Humke et al. (1975).

To get a handle on the elements of natural diversity we developed an approach to the classification of element types that includes plant communities, aquatic habitats, geologic features, and "special" species (i.e., endangered or other significant species). Figure 1 illustrates the element occurrence and the classification strategies. The classification system

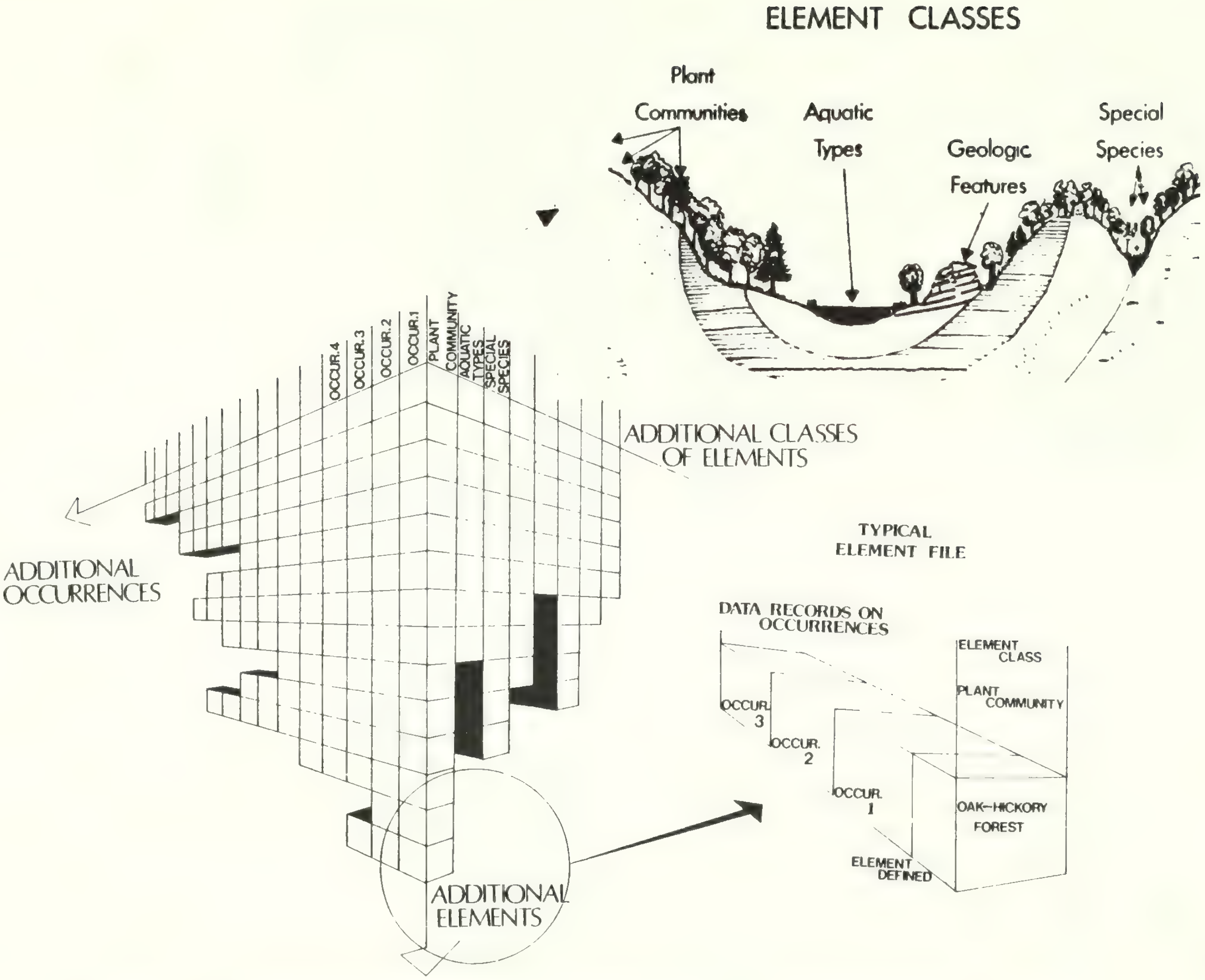


Figure 1. Conceptualization of element occurrences and classification strategy.

consists of element classes and elements which are represented by the right half of the data block in the diagram. New classes or elements may be added to the classification as needed. The left half of the data block represents occurrences of individual elements. We can collect and, therefore, easily compare reported occurrences of a particular element; e.g., one example of an Oak-Hickory forest can be compared directly with other examples of Oak-Hickory forest. A more detailed discussion of the classification system was presented by Robert Jenkins earlier at this conference.

To protect and maintain ecological diversity it is essential for us to have easily accessible information about the elements of natural diversity--the existence, characteristics, condition, numbers, status, location, and distribution of their individual occurrences. We feel a data base containing the following broad units of information is therefore necessary:

- element types (defined by the classification system),
- element occurrences,
- managed areas, and
- sources of information.

The data base, in essence, consists of a collection of these units of information. These units are aggregated into individual files, the data structure and interrelationship of which are crucial to the system implementation and use. Initially all these files can be thought of as manual files; an additional advantage is added through computerizing certain ones. The computer facilitates rapid retrieval, permutation, revision, analysis, and report generation.

It must be noted that the enlarged capability provided by the computer is not based on any sophisticated procedures but rather on the computer's ability to perform the same manual tasks of searching, comparing, merging, and sorting with enormous speed. In order to fully utilize manual as well as computerized files, it is important to recognize the advantages and disadvantages of various forms of data and file structures, always coupling manual approaches with computer-mediated methods.

DESIGN CONSIDERATIONS

Many groups have carried out ecological inventories and compilation efforts and have utilized information management systems. In the interest of brevity this report will not review the literature on previous efforts.

The Nature Conservancy has played a key role in many ecological inventory efforts, and the many lessons learned from past experience in our participation with ecological inventories have been applied to the development of the ecological information management system. The following are among the most outstanding pitfalls that past experiences have taught us to avoid in designing our ecological information system:

- striving to capture as much data as possible until time, patience, and resources are depleted, without collecting and prioritizing comparable data at all levels of the inventory process;

- attempting to computerize every bit of information collected, and hoping that the computer can sort everything out later in a cost-effective manner;

- failing to integrate the role of data processing functions in the inventory so that the information system is peripheral instead of a fundamental part of the entire process;

- implementing a large-scale system before the functional requirements of the system have been clearly defined;

- attempting to record all data in one catch-all record format;

- designing the full scale system without building smaller scale prototypes first, and failing to run demonstrations of the system to allow users to test the utility of the system;

- failing to keep a realistic view of automated systems limitations;

- neglecting to make full use of varying file organizations and neglecting to design a simple, modular system; and

- failing to discard any part of the system which does not meet user requirements.

STRUCTURING DATA

Problems facing large scale ecological inventory projects have always included: how much information can be collected within a specified time and budget versus how much is actually needed for the desired analysis and decisionmaking, and how should data be structured and systematized to maximize our search, retrieval, and analytical capabilities. Our approach is to carefully tailor the data collection process by prioritizing certain data categories. This results in the "layered" data structure shown in Figure 2. The Lowest Common Denominator (LCD) level of data consists of relatively short and standardized data categories. The LCD records in essence are abstracts that provide an infrastructure to facilitate recording and organizing an adequate amount of data for efficient analysis of the elements of natural ecological diversity. The LCD data structure is designed to accomplish four general objectives:

- acquire comparable data coverage on each item;

- standardize terminology;

- improve speed of access and ability to permute those categories of information most useful to protection planners, and various other uses; and

- provide clear feedback on key data gaps.

The LCD data structure is oriented to capturing a few important data items. Attention can therefore be focused on acquiring complete, LCD-level

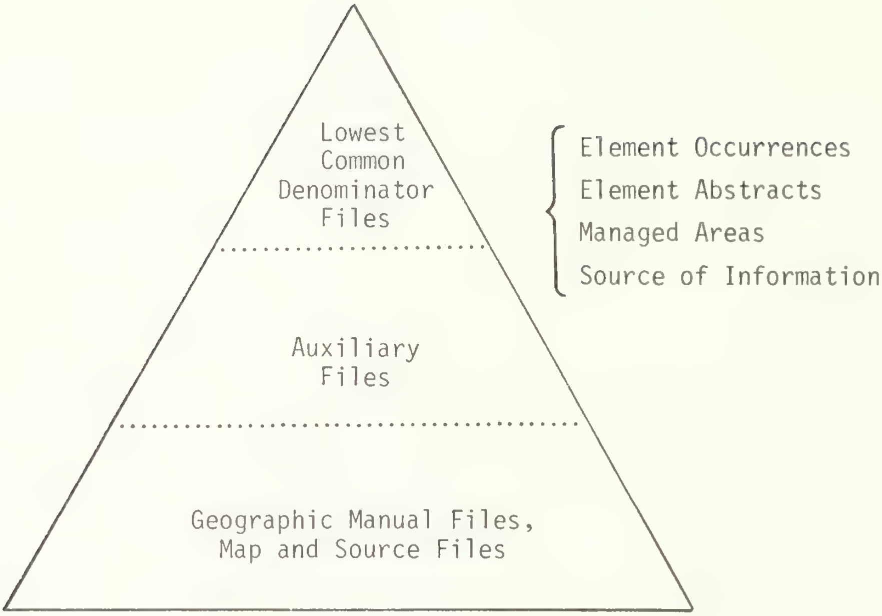


Figure 2. Layered data structure concept.

information for all sites or element occurrences, rather than on encoding massive amounts of detailed material for relatively few items. The LCD record form forces standardization of the data field terminology as well as controlling some of the characteristics of the actual data. Such an approach gives a very broad base of comparable information.

The terseness and standardization of the LCD data structure make it easy to store and manipulate data via computer. Even very complex data combinations can be analyzed quickly and economically with the help of modern data processing techniques. For example, using the automated LCD system an analyst can determine in as little as half an hour which element occurrences out of several thousand are within a certain county, are not on protected land, and are considered threatened. The same system can tally the number of occurrences of each element for which LCD data has been compiled, thus highlighting information gaps as well as eventually providing an objective tool for assessing element rarity.

LCD FILES

There are four basic LCD record structures:

The LCD Element Abstract Record is currently stored in manual files, although experiments are being made to determine how it can best be computerized. It is linked to the element classification and provides standard information on distinguishing characteristics of each element type; in short, it is a resource catalog.

The LCD Element Occurrence Abstract Record incorporates an adequate amount of data for analysis of the occurrence, number, status, location, and distribution of the elements defined by the classification. Each record in the LCD-Element File (LCD-ELF) contains information on a separate element occurrence. Appendix A shows the format for the LCD-ELF Records.

The LCD Site Abstract Record is a repository for managed area type data. Each record in the LCD Site File (LCD-FORSITE) describes a site's location, size, ownership, the level and means of protection afforded to the site, and the general characteristics of natural diversity that the site represents. The LCD-FORSITE record format is shown in Appendix B.

The Source of Information Abstract Record serves as a structured bibliographic repository and is presently stored in manual files.

AUXILIARY FILES

After we are certain that comprehensiveness of data coverage has been achieved, additional data are incorporated into auxiliary files. The auxiliary records are automated, flexible data structures which can house variable data lengths and formats. The auxiliary records can maintain additional data categories not found in the LCD records or can be used to facilitate the merging of related data to form a single, integrated, inverted file. We cannot identify, with any certainty, how many categories of detailed data will prove to be useful to the system users over time, nor predict the amount of data that will become available as researchers fill existing information gaps. Therefore, rather than limit the system capability by assigning just LCD data structures or delimiting one large data structure to store everything, we have developed multiple, independent auxiliary files that can handle different data structures. New types of information can be made available by designing new auxiliary records, by inverting existing files, or merging with new or existing auxiliary files.

For example, we have organized auxiliary records into topical files such as bird species with each data entry for a single species tagged with site locators (see Appendix C for an example of a bird and mammal species auxiliary file). The data entries are also coded to indicate which species are included in a state or national list of endangered species. Current and imminent auxiliary files include the following:

- Plant Communities
- Physiographic Provinces
- Geologic
- Aquatic
- Mammals
- Birds
- Reptiles and Amphibians
- Fishes
- Endangered Fauna
- Digitized Boundaries for elements occurrences and managed areas

The record structures within each file can be easily reformatted and new auxiliary files can be added or deleted depending on the information and end results desired. Faster searches are made possible through data reduction as well as extension by having the flexibility to rearrange the data structures.

MANUAL FILE STRUCTURES

The broadest level of structured data assemblage occurs at the manual level. The manual files are used to store the bulk of ecological data that is inefficient to computerize. The manual files accommodate all the compiled textual matter, lists of information sources, maps, etc.

Our decision to design multiple manual filing structures to augment computerized files was based on common sense and our past experience. We have found that some types of information can be retrieved more efficiently from manual files than from computers. Storage and retrieval cost and programming complexity increase and the general reliability of the system decreases in proportion to the amount of information and number of variables being computerized.

GEOGRAPHIC MANUAL FILE

The basic unit of geographic information is the 7.5 minute topographic quad map. Other topographic or smaller scale maps are used for areas within the states that may not have 7.5 minute topo maps. We have developed coding conventions for plotting and indexing onto maps the boundaries of sites and element occurrences. The quad maps are organized by the Universal Map Code location system (Weber and Gregory, 1975). This coding system permits easy map and information cross-referencing, access, and retrieval. Each topographic map cross-indexes to a manual file.

INFORMATION FLOW--CYCLICAL DATA MANAGEMENT AND USE CONCEPT

Figure 3 depicts the groupings of key system functions and activities and shows their interrelations in the overall cyclical data management concept. The compilation of data from various sources, assignment of index codes, and storage in geographic manual files and in the computer system are illustrated.

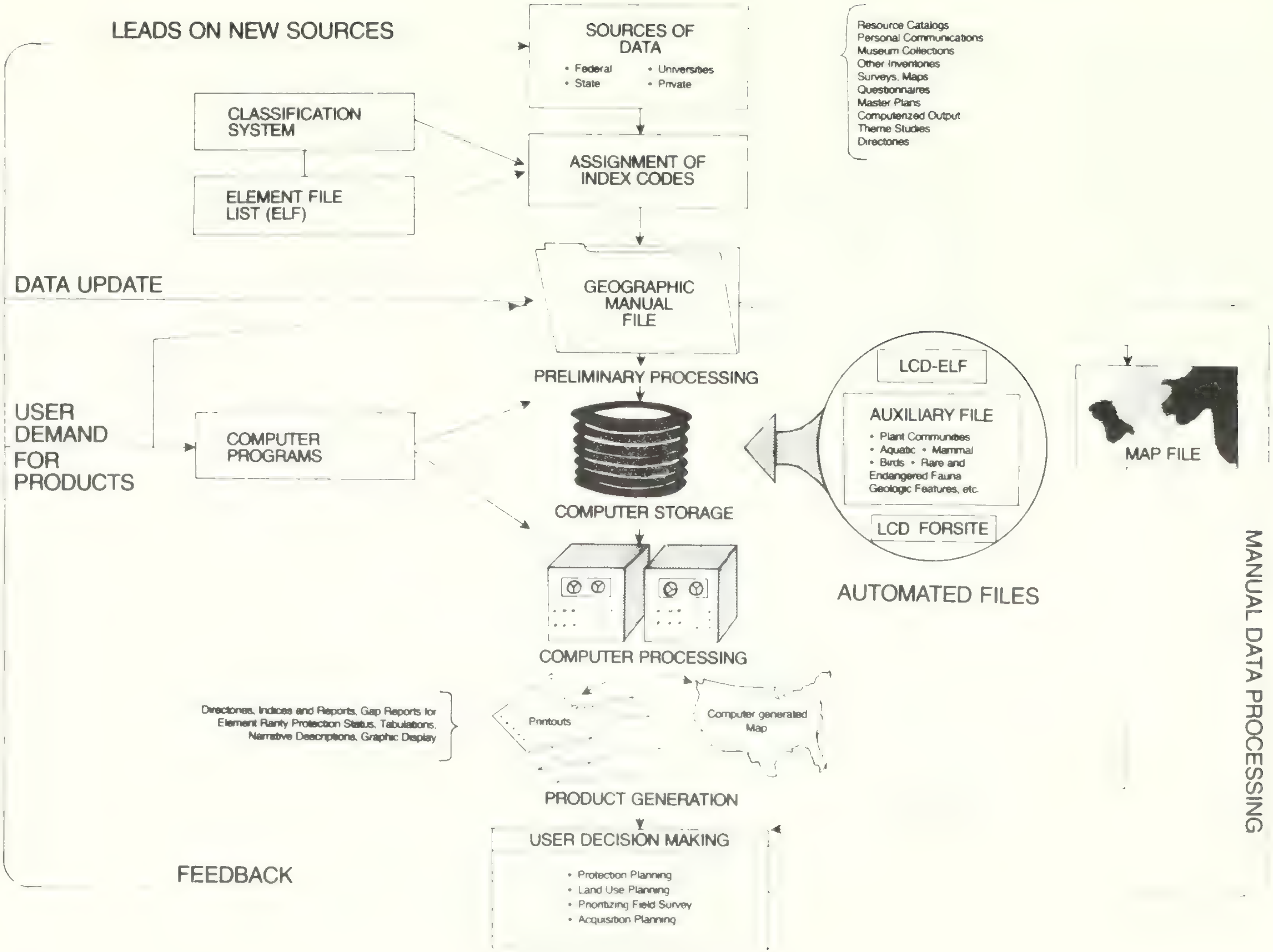


Figure 3. Cyclical data management concept.

FILE STRUCTURES AND SUPPORTING COMPUTER PROGRAMS

Organization of manual filing structures to complement automated files is one of the most neglected aspects of many data base designs. The Nature Conservancy system design is balanced precisely because of the attention given to cohesive organization of the total data base. The several manual files are each organized for efficient reference to the specific type of data they contain. The computerized files contain primarily summary level information in relatively short records that make data easy to permute and access. It is important to anticipate the uses and products of various file structures and to optimize for these purposes in design. All files, whether automated or manual, are cross-referenceable. The automated files are maintained and manipulated through a set of modular computer programs.

CONTINUITY OF DATA COLLECTION

It is hardly justifiable to collect, organize, and computerize data for a single ad hoc application or to consider the data base fully utilized by publication of a single hardbound report. The data base must be enriched continuously to reflect the most current and comprehensive information available.

The system concept presented here is balanced by the following characteristics:

1. The interaction between the end user and the system is effective and occurs at several levels. The data in the system is enriched by providing information to users for their critical evaluation and feedback.

2. Flexible use is made of conventional and modern techniques of processing and data storage. Although automated processes using a computer are employed in our system, conventional manual file storage is the backbone of the system. Our computer methods are invoked when it is advantageous to do so based on considerations of resources, time, and need.

3. Components of the system may be brought to bear on varied problems as required because of their modular, independent implementation.

USERS OF THE SYSTEM

User evaluation and feedback are integral parts of the overall cyclical data management concept. Users define queries, generate product demands, contribute to the ongoing processes of updating and refining data, generate new leads to information sources, and redefine functional requirements.

Users are of two kinds, the one requiring information for decisionmaking and research application and the other being interested primarily in inventory and data base enhancement. Potential users of the system include:

- organizations that operate as part of the Federal and state efforts for wildlife habitat assessment and protection management, and

- private organizations of professionals such as scientists, systematists, and land use planners involved in inventory, protection, and land use planning.

A general query processing diagram that illustrates how user queries can be handled is shown in Figure 4. A user usually requests information by phone or letter. The user query must be specified in such a manner that a decision

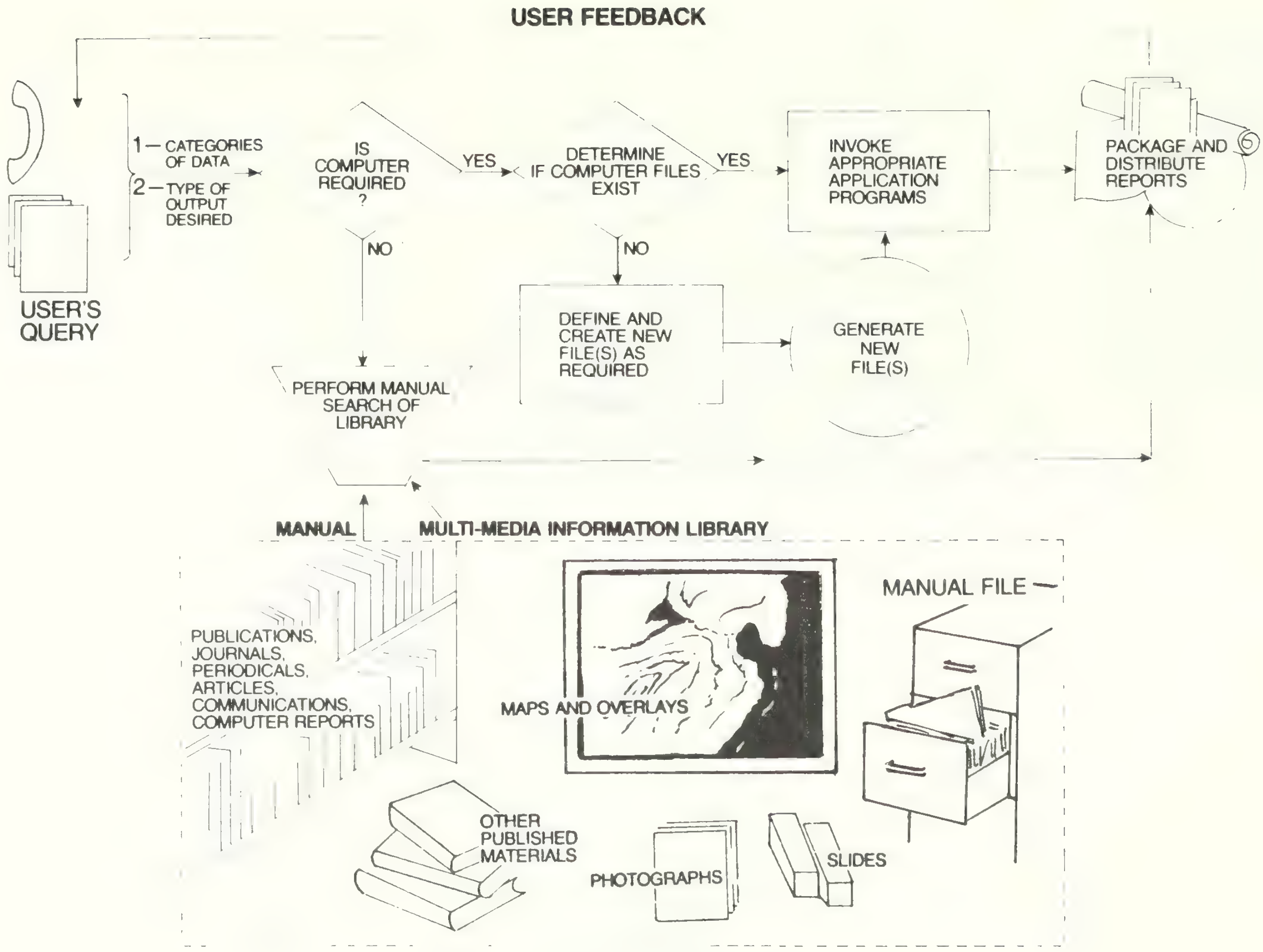

USER FEEDBACK
USER'S QUERY
1 — CATEGORIES OF DATA
2 — TYPE OF OUTPUT DESIRED
IS COMPUTER REQUIRED ?
YES
NO
DETERMINE IF COMPUTER FILES EXIST
YES
NO
INVOKE APPROPRIATE APPLICATION PROGRAMS
PACKAGE AND DISTRIBUTE REPORTS
DEFINE AND CREATE NEW FILE(S) AS REQUIRED
GENERATE NEW FILE(S)
PERFORM MANUAL SEARCH OF LIBRARY
MANUAL
MULTI-MEDIA INFORMATION LIBRARY
PUBLICATIONS, JOURNALS, PERIODICALS, ARTICLES, COMMUNICATIONS, COMPUTER REPORTS
MAPS AND OVERLAYS
MANUAL FILE
OTHER PUBLISHED MATERIALS
PHOTOGRAPHS
SLIDES

Figure 4. Processing user queries.

can be made regarding the appropriate files to search. In addition, the user specifies the type of output desired. A decision is then made to begin the search either in manual or computerized files.

If the query does not warrant a computer search, then the information is retrieved directly from the manual files (the multimedia information library). If the user requires a type of information that can be retrieved more easily by computer, then appropriate files and programs are brought to bear. Usually queries will involve a sequence combination of manual and computerized searches. End products include computer printouts, Xerox reproductions, maps, and computer plots. The feedback loop is completed upon delivery and user evaluation of the product.

PRODUCT GENERATION

The modularity of both the files and software allows us to respond to a large variety of user requests in a timely and cost-effective manner.

For example, a user might request information on all the sites containing Red Spruce forest (SAF-32). We would need only to query the LCD-ELF files to receive data on all sites containing that forest cover type. With this information in hand, the user could then request data from LCD-FORSITE and auxiliary files to receive information on other species of fauna and flora known to occur on the sites containing Red Spruce forest. It is also possible to retrieve information based on data commonality. For example, one can obtain specific information about all element occurrences sharing common attributes such as protection status, locations, site owners, etc. Many questions regarding ecological considerations can be potentially addressed, for example:

- the criticality or significance of element occurrences,
- the level of protection given element occurrences or managed areas relative to the ownership of the land, and
- the perspective necessary for estimating the relative significance of any single site.

FILE AND DATA LINKAGES

Search through multiple files is made possible and efficient by the use of index codes. Each site in the system has an index code which serves as a key to all of the individual related files. The index code is used to organize computer, manual, and map files. Each element occurrence also has its own unique code which is used to cross-reference all the data stored in its related automated and manual files. The files are linked logically even though they are stored in separate media and/or locations. Figure 5 shows the index code linkages among the LCD-ELF, LCD-FORSITE, auxiliary, manual, and map files. A user can obtain a detailed, composite picture of the data coverage for any given geographic area by using the index code to retrieve the data from each auxiliary file and the LCD file.

In Appendix D an overlay method is depicted that shows all the data sharing a common geographic boundary, the locations of managed area sites, occurrences of elements, birds, and mammals found on the Tennessee Manchester topographic map. In Appendix A selected printouts of the element occurrences located on the 7.5 minute topographic map for Manchester quadrangle are provided. Appendix B provides the LCD-FORSITE printouts for the Research Natural Areas located on Manchester quad. Appendix C contains printouts generated

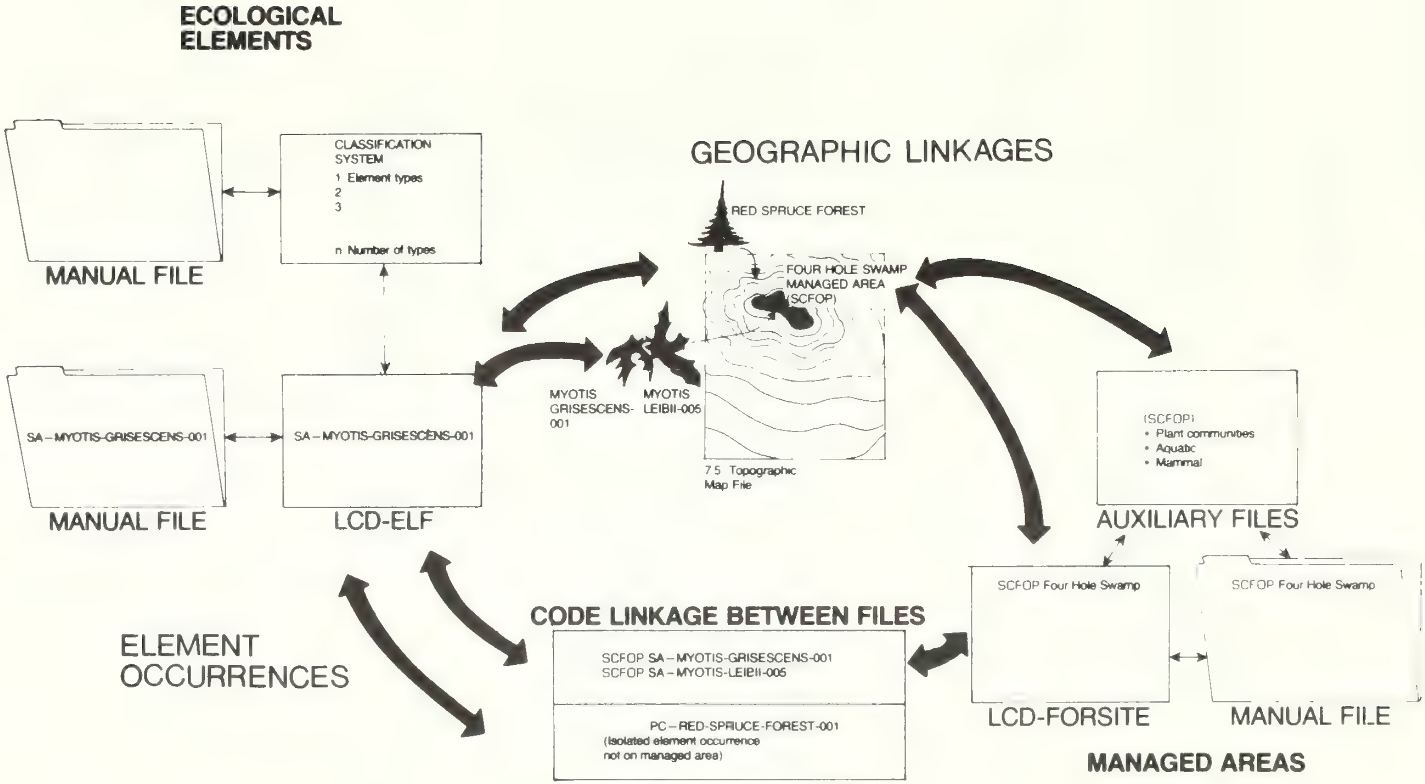


Figure 5. Code linkages among files.

from the auxiliary files showing listings of birds and mammals found on the managed area sites and also located on Manchester quad. The Bird and Mammal lists are indexed by family, common, and scientific names. The index codes INSIP and INGOP provide the linkage for retrieving data based on quad code and site commonality.

GENERAL DESCRIPTION OF COMPUTER PROGRAMS

The Nature Conservancy has designed and implemented a collection of general purpose and application-specific computer programs to maintain and utilize computerized ecological files. The three major collections of programs and their file relationships are depicted in Figure 6 and described below:

1) LCD-ELF (programs for handling State Heritage Element File data);

2) LCD-FORSITE (programs for handling managed area file data); and

3) General Purpose programs.

LCD-ELF

The LCD-ELF system consists of a data base (the Element Occurrence File) and six program modules. The program modules offer the capability to create and manage the data base, permit modifications to individual records, provide retrieval and certain statistical and reporting capabilities, supply routines for plotting the ecogeographical data, and load data from disk to tape and back to disk. The search and reporting capabilities allow the system user to cross-reference, permute, compare and analyze data on the existence, status, number, distribution, and characteristics of element occurrences. The power of the search module makes data accessible in a variety of ways that can be very useful for determining the geographical distribution, relative rarity, and protection status of species, habitats, and other elements of diversity.

We have designed the automated LCD-ELF system with the user in mind; someone with little or no computer experience can easily learn to run the programs. A user manual and reference document (Moyseenko et al. 1976) fully describes the usage and applications of the programs. The system is currently batch-mode supported, and is installed at seven state agencies and TVA computer installations.

LCD-FORSITE

The LCD-FORSITE system consists of a data base on managed areas and a collection of modular programs. These programs provide the file maintenance capabilities of adding, deleting, and updating records. They allow the system user to search the files for records containing specific groups of data. They also produce formatted listing of the search results. The search program includes an option to punch latitude and longitude coordinate points which can then be linked with the LCD-ELF mapping program. The mapping program translates the coordinates into instructions which direct a Calcomp plotter to draw the locations of the data on transparent paper. The mapping products can then be used as overlays for a variety of geographic base maps.

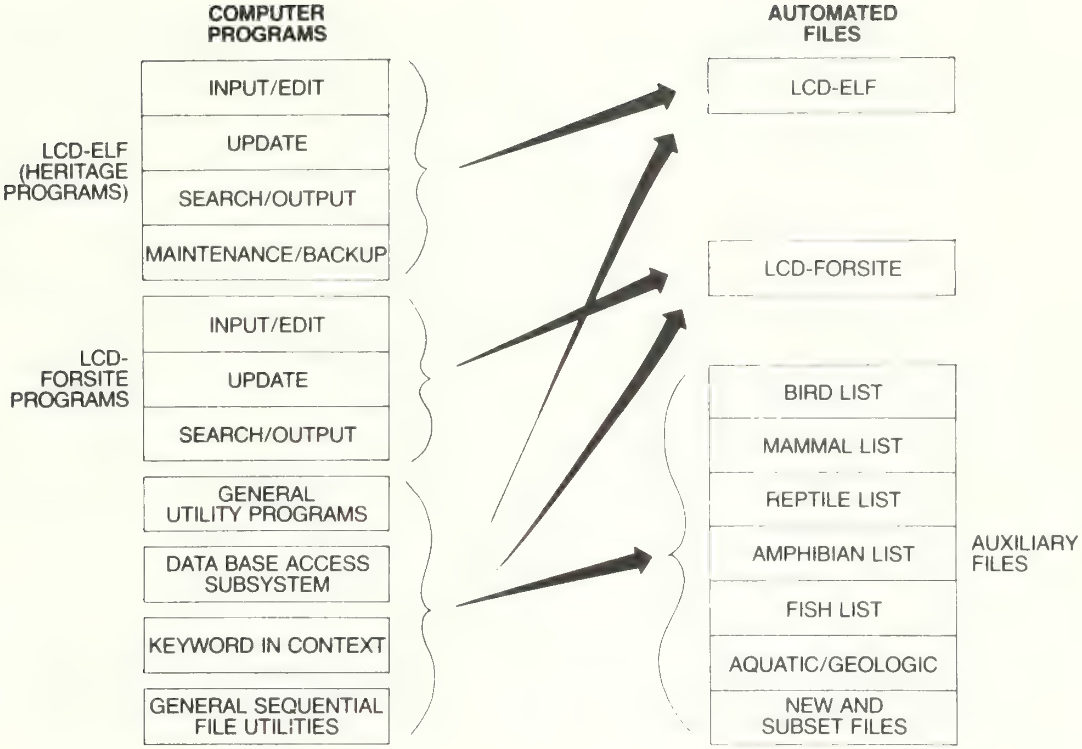


Figure 6. Computer programs and file relationships.

GENERAL PURPOSE PROGRAMS

The General Purpose Programs enhance the data handling, analysis, and output capabilities of the LCD-ELF and LCD-FORSITE programs. They may be regarded as tools for meeting processing needs concerning a variety of different files. The General Purpose programs maintain and process the auxiliary files and can also be applied to other sequential files. They include original software developed in-house as well as software packages obtained from other agencies.

It is virtually impossible at the outset to predict every potential system requirement and to program accordingly. For this reason, we write new programs, or incorporate appropriate modules from other agencies into our total system design, as the need for them arises. A brief discussion of the major General Purpose programs in current use follows:

ADHOC

ADHOC is The Nature Conservancy's in-house general purpose utility software. Each program in the ADHOC package can perform a discrete record or file handling function and can be applied to most sequential file structures. By choosing from among the different ADHOC programs, a programmer can perform data processing tasks as simple as record selection based upon a single criterion or as complex as production of a cross-referenced, indexed directory. A report program allows the programmer to specify titles, page footings, input, and print formats so that a complex report can be set up in a couple of hours. The package makes possible a wide range of exceptional data processing tasks.

Keyword in Context (KWIC)

The Nature Conservancy has acquired IBM's Keyword in Context programs. Basically this software allows the user to have specific words selected from a body of text and then generated as an index to the text. We have found it useful in the analysis of computerized descriptive text and apply it principally to the short description section of the LCD-ELF and LCD-FORSITE files. Interested readers may obtain more information about the KWIC by contacting their local IBM representative.

FHWA Mapping Software, State, and Geographic Base File

The Nature Conservancy also acquired the mapping software and geographic boundary files used by the Federal Highway Administration (FHWA 1970). The boundary file contains digitized polygon boundaries which describe the state and county outlines for continental United States. This package enables us to accurately reproduce state and our county boundaries at any given scale for two major geometric projections. The map outlines can be reproduced on transparent paper to serve as base map overlays for the element occurrences and managed area locations. The FHWA software and data structure complement The Nature Conservancy's in-house mapping and Element File programs.

CONCLUSIONS

Our inventory and data management concept is referred to as "balanced" because of the attention given to the cohesive organization of the entire data base including the automated and manual files. The overall data base infrastructure is designed to simplify the tasks of storing and retrieving data whether they be manual or computer-augmented operations. Most of the files can be maintained by manual operations alone, but we have carefully designed and implemented a collection of computer programs that are high cost-effective, efficient, and responsive. These are designed to greatly speed up the manual tasks of searching, comparing, merging, sorting, and report writing.

The overall data organization must not only serve as an efficient storage and retrieval medium but also facilitate the data inventory systematization and information exchange. We have carefully established the requirements and priorities for data assemblage. The emphasis of our inventory is always on achieving data coverage which is both comprehensive and comparable so that analysis, comparison, and evaluation of the data can be made at different stages of the inventory. The information system is especially geared for handling and managing data on rare and endangered biological species, and for analysis of the existence, status, numbers, condition, characteristics, and distribution of the elements of natural ecological diversity.

Our State Natural Heritage Programs and national ecogeographical information system focus on maintaining ecological diversity by identifying priorities for ecological preservation and planning. As the data base matures, the system will be able to serve many uses. The comparative methodology by which the relative criticality of various landspaces can be assessed will be of great utility in the fields of environmental impact assessments and land use planning.

We must lay aside the notion that ecological inventories can ever be truly completed--they may become refined and mature, yes, but not complete. After all, we are dealing with dynamic processes and the data base must be continuously enriched. Given a limited amount of funding and time, we must carefully tailor the collection and prioritize certain data. If we can, for example, get LCD-type coverage for all the classes of data, we have at least achieved a certain level of comparable data coverage--and that is no small accomplishment.

More attention should be given to coupling manual approaches with computer mediated methods and always keeping in mind computer systems limitations. Also, more attention should be given to structuring the data, regardless of whether it will be computerized or not--after all, what good is a data base if we cannot get to the data effectively when we need it?

LITERATURE CITED

Federal Highway Administration. 1970. FHWA State/County Data Bank Project Document, Data Base Documentation, and Modules.

Humke, J.W., B. Tindall, R.E. Jenkins, H.L. Wieting, Jr., and M.S. Lukowski. 1975. The Preservation of Natural Diversity: A Survey and Recommendations. The Nature Conservancy, Arlington, Virginia.

Jenkins, E. 1976. Maintenance of Natural Diversity: Approach and Recommendations. Trans. Wildl. Nat. Resour. Conf. 41:441-451.

Jenkins, R.E. 1975. Ecology forum: heritage programs: inventory progress report. The Nat. Conservancy News 25(2):26-27.

Moyseenko, H.P. 1974. Ecology forum: a comprehensive natural areas program. The Nat. Conservancy News 25(2):19-20.

Moyseenko, H.P., R.E. Jenkins, L.A. Miller, and S. Woodall. 1976. Lowest Common Denominator Element File, The Nature Conservancy, Arlington, Virginia.

Weber, S.G., and R.P. Gregory. 1975. Universal Map Code (A 7-1/2 Minute Quadrangle Identification System), Tech. Note B-10, For., Fish., and Wildl. Dev., Tennessee Valley Authority, Norris. 12 pp.

```
           INDEX KEY  SP AMBYSTOMA TALPOIDEUM 012   (V)
               STATE  TN                                                    COORDINATES  352440N860450W    (C)
              COUNTY  031                                                   USGS QUAD MAP NAME  MANCHESTER
          INDEX CODE  10.302.012.3508641                                    SPECIAL STATUS
   NAME OF SITE/AREA  AEDC RESERVATION                                      PROTECTION STATUS  3
    NUMBER OF OWNERS  01                                                    DATE OF INFORMATION   750115
     PRINCIPAL OWNER  US AIR FORCE                                          SIZE
      SOURCE OF LEAD  CHARLES SULLIVAN  HUMBER DRIVE  NASHVILLE TN
 GENERAL DESCRIPTION  MOLE SALAMANDER  A LARGE POPULATION INHABITS THIS AREA, AND IT IS A MAJOR BREEDI
                      NG SITE FOR THIS SPECIES.  THE FOUR OTHER AMBYSTOMATIDS KNOWN TO OCCUR IN TENN
                      (TIGRINUM, TEXANUM, MACULATUM, AND OPACUM) ALSO BREED HERE, MAKING THIS A UNIQUE
                      SALAMANDER COMMUNITY.
CONTENTS OF MANUAL FILE     DIRECTIONS    BOUNDARY ON TOPO         PHOTOS    FIELD SURVEY    OWNER INFO    REFERENCES
                                                 B                                                0


           INDEX KEY  SP ARDEA HERODIAS 003   (V)
               STATE  TN                                                    COORDINATES  352445N860405W    (U)
              COUNTY  031                                                   USGS QUAD MAP NAME  MANCHESTER
          INDEX CODE  10.505.003.3508641                                    SPECIAL STATUS
   NAME OF SITE/AREA  ARNOLD ENGINEERING DEVELOPMENT CENTER                 PROTECTION STATUS  2
    NUMBER OF OWNERS  01                                                    DATE OF INFORMATION   750000
     PRINCIPAL OWNER  US AIR FORCE                                          SIZE
      SOURCE OF LEAD  DAVID FITTS  DEPT BIOL  UT-MARTIN  MARTIN TN
 GENERAL DESCRIPTION  GREAT BLUE HERON  COLONY IS IN SINKING POND NATURAL AREA, IT HAS EXISTED SINCE
                      AT LEAST 1965, EACH YEAR CONTAINING 15-25 NESTS.  AEDC OFFICIALS ARE AWARE OF
                      THIS COLONY AND ITS UNIQUE QUALITIES.

CONTENTS OF MANUAL FILE     DIRECTIONS    BOUNDARY ON TOPO         PHOTOS    FIELD SURVEY    OWNER INFO    REFERENCES
                                                 E                                                0             R
```

APPENDIX A

SELECTED PRINTOUTS OF ELEMENT OCCURRENCES LOCATED ON MANCHESTER TOPOGRAPHIC MAP

APPENDIX B

PRINTOUTS FOR THE RESEARCH NATURAL AREAS LOCATED ON MANCHESTER TOPOGRAPHIC MAP

```
SITE NAME                                          STATE COUNTY                              SIZE     CUAD          LAT/LONG
                                                                                           (ACRES)    CODE

GOOSE POND UPLAND SWAMP RESEARCH NATURAL AREA       TN    COFFEE                              152    3508641     3523  N0860115W
      INDEX: TN0[illegible]
              INFORMATION DATE (YEAR MO. DAY):     76/03/29
              ESTABLISHMENT DATE (YEAR MO. DAY):     /  /
              ELEVATION (FT)--MIN:  1100:  MAX:  1100
              OWNERSHIP/ADMINISTRATIVE AGENCY:  USA, AIR FORCE,ARNOLD ENGINEERING DEVELOPMENT CENTER%,PRIVATE%
              CONTACT:  COMMANDING GENERAL,ARNOLD ENGINEERING DEVELOPMENT CENTER, TULLAHOMA,TENN 37388
              OFFICIAL STATUS:  RESEARCH NATURAL AREA(FCER)
                                ELIGIBLE NATIONAL LANDMARK
              PROTECTION STATUS:  PROTECTED
              THREAT: UNKNOWN

       AVAILABLE DATA: N=NO DATA/SITE: U=UNSPECIFIC: L=LIMITED: S=SUBSTANTIAL: R=RECEIVED--IN TNC FILES.

       LOCATION--MAP:              |   |   |   |   | R |   CLIMATOLOGIC:                 |   | U |   |   |   |
              DESCRIPTION:         |   |   |   |   | R |   SPECIES LISTS--FLORA:         |   |   |   |   | R |
       BOUNDARY--MAP:              |   |   |   |   | R |                  MAMMALS:       | N |   |   |   |   |
              DESCRIPTION:         |   |   |   |   | R |                  BIRDS:         | N |   |   |   |   |
       GEOLOGIC--SURFACE MAP:      | N |   |   |   |   |                  REPTILES:      | N |   |   |   |   |
              DESCRIPTION:         |   |   | L |   |   |                  AMPHIBIANS:    | N |   |   |   |   |
              SUBSURFACE MAP:      | N |   |   |   |   |                  FISH:          | N |   |   |   |   |
              DESCRIPTION:         | N |   |   |   |   |                  INSECTS:       | N |   |   |   |   |
       TOPOGRAPHIC--MAP:           |   |   |   |   | R |                  MOLLUSKS:      | N |   |   |   |   |
              DESCRIPTION:         |   |   | L |   |   |   RESEARCH HISTORY:             |   |   |   | S |   |
       SOILS MAP:                  |   |   |   |   | R |   FACILITIES:                   | N |   |   |   |   |
              DESCRIPTION:         |   |   |   |   | R |   LAND USE--SITE:               |   |   |   |   | R |
       HYDROLOGIC--MAP:            | N |   |   |   |   |         SURROUNDING AREA:       |   |   |   |   | R |
              DESCRIPTION:         | N |   |   |   |   |   MANAGEMENT:                   |   |   | L |   |   |
       VEGETATION--COVER TYPES MAP:|   | U |   |   |   |   CONTACTS:                     |   |   | L |   |   |
              DESCRIPTION:         |   |   |   |   | R |   COMPILED DATA:                |   |   | L |   |   |
       AERIAL PHOTOS/IMAGERY.      |   |   |   |   | R |   BIBLIOGRAPHY:                 |   | U |   |   |   |
       GROUND/SITE PHOTOS:         |   |   |   |   | R |
       ENDANGERED SP--FLORA:       | N |   |   |   |   |
                      FAUNA:       | N |   |   |   |   |

       SIGNIFICANCE:

                 A LARGE SINKHOLE TYPE BASIN. IT EXHIBITS A CATTAIL-SAWGRASS VEGETATION. THE ONLY
                 KNOWN NESTING STATION FOR BLUE-WINGED TEAL IN THE STATE. OPEN MARSH WITH AN
                 [illegible] BUFFER (APPROX-100 OAK-HICKORY FOREST(WHITE OAK DOMINATED,SECOND GROWTH).IN
                 MARSH. 7 VEGETATION ZONES CONTAINING 28 VASCULAR PLANT TAXA.IN THE DEEPEST WATER
                 IS A LOW COVER OF FLOATING AQUATIC PICKERELWEED. A RED MAPLE & SWEETGUM TRANSI-
                 TION ZONE BETWEEN THE MARSH AND THE WHITE OAK FOREST.CHARACTERISTIC OF THE HIGH-
                 LAND RIM SECTION OF THE INTERIOR LOW PLATEAUS PHYSIOGRAPHIC PROVINCE. LOCATED 7
                 MILES SE OF MANCHESTER.FLORISTICALLY SIGNIFICANT BECAUSE OF DISJUNCT PLANT SPP.
```

```
SITE NAME                                                STATE COUNTY                                    SIZE        QUAD              LAT/LONG
                                                                                                        (ACRES)      CODE

SINKING POND UPLAND SWAMP RESEARCH NATURAL AREA    TN     COFFEE                                       394    3508641      3524  N08604  W
      INDEX: TNSIP
               INFORMATION DATE (YEAR MO. DAY):    76/03/05
               ESTABLISHMENT DATE (YEAR MO. DAY):      /  /
               ELEVATION(FT)--MIN.  1035:  MAX:  1060
               OWNER/ADMINISTRATIVE AGENCY:  USA. AIR FORCE.ARNOLD ENGINEERING AND DEVELOPMENT CENTER
               CONTACT:  COMMANDING GENERAL.ARNOLD ENGINEERING & DEVELOPMENT CENTER. TULLAHOMA.TN. 37388
               SPECIAL STATUS:  RESEARCH NATURAL AREA(FCER)
                                ELIGIBLE NATIONAL LANDMARK
                                SAF NATURAL AREA
               PROTECTION STATUS:  PROTECTED
               THREAT UNKNOWN

          AVAILABLE DATA: N=NO DATA/SITE: U=UNSPECIFIC: L=LIMITED: S=SUBSTANTIAL: R=RECEIVED--IN TNC FILES.

          LOCATION MAP:               |    |    |    |    | R |    CLIMATOLOGIC:                |    | U |    |    |    |
                   DESCRIPTION:       |    |    |    |    | R |    SPECIES LISTS--FLORA:        |    |    |    |    | R |
          BOUNDARY MAP:               |    |    |    |    | R |                   MAMMALS:      | N |    |    |    |    |
                   DESCRIPTION:       |    |    | L |    |    |                   BIRDS:        | N |    |    |    |    |
          GEOLOGIC--SURFACE MAP:      | N |    |    |    |    |                   REPTILES:     | N |    |    |    |    |
                   DESCRIPTION:       |    |    | L |    |    |                   AMPHIBIANS:   | N |    |    |    |    |
                SUBSURFACE MAP:       | N |    |    |    |    |                   FISH:         | N |    |    |    |    |
                   DESCRIPTION:       | N |    |    |    |    |                   INSECTS:      | N |    |    |    |    |
          TOPOGRAPHIC MAP:            |    |    |    |    | R |                   MOLLUSKS:     | N |    |    |    |    |
                   DESCRIPTION:       |    |    | L |    |    |    RESEARCH HISTORY:            |    |    |    | S |    |
          SOILS MAP:                  |    |    |    |    | R |    FACILITIES:                  | N |    |    |    |    |
                   DESCRIPTION:       |    |    |    |    | R |    LAND USE--SITE:              |    |    | L |    |    |
          HYDROLOGIC MAP:             | N |    |    |    |    |          SURROUNDING AREA:      |    |    | L |    |    |
                   DESCRIPTION:       |    |    | L |    |    |    MANAGEMENT:                  |    |    | L |    |    |
          PLANT COMMUNITIES MAP:      |    | U |    |    |    |    CONTACTS:                    |    |    | L |    |    |
                   DESCRIPTION:       |    |    |    |    | R |    COMPILED DATA:               |    |    |    | S |    |
          AERIAL PHOTOS/IMAGERY:      |    |    |    |    | R |    BIBLIOGRAPHY:                |    | U |    |    |    |
          GROUND/SITE PHOTOS:         |    |    |    |    | R |
          ENDANGERED--FLORA:          | N |    |    |    |    |
                   FAUNA:             | N |    |    |    |    |

               SIGNIFICANCE:

                         SAF-92. PRIMARY FOREST TYPE: SWEET GUM-NUTTALL OAK (111 ACRES). K-100 OAK-
                         HICKORY FOREST. CVT:SAF-96 OVERCUP OAK. WATER HICKORY:SAF-102 WATER TUPELO. GREA
                         T BLUE HERON ROOKERY:AV. NO. OF NESTS=17PER YEAR. WOOD DUCK.BELTED KINGFISHER.FL
                         YING SQUIRREL.          245 ACRES MAINLY WHITE OAK-RED OAK. HICKORY WITH 15 ACRE
                         PLANTED LOBLOLLY PINE & 27 ACRES DOMINATED BY E.RED CEDAR. GENERAL AREA IS OAK-
                         HICKORY. 149 ACRES CONSIST OF BOTTOM LAND HARDWOOD WITH A FEW STANDS OF RIVER
                         BIRCH. TOPOGRAPHY: LEVEL WITH KARST. GEOLOGY & SOILS: MOUNTVIEW. DICKSON.SANGO.
                         GUTHRIE. PREDOMINANTLY GUTHRIE SILT LOAM. TOPO MAP:MANCHESTER.1972.7.5 MIN.SOIL.
```

APPENDIX C

INDEX TO MAMMALS LOCATED ON MANAGED AREAS
MANCHESTER TOPOGRAPHIC MAP

PREPARED BY
THE NATURE CONSERVANCY

INDEX TO MAMMALS BY COMMON NAME

PAGE 1
OCTOBER 1976

FAMILY NAME	COMMON NAME	SCIENTIFIC NAME S I T E C O D E S
CANIDAE	GRAY FOX	UROCYON CINEREOARGENTEUS TNSIP ( )
CASTORIDAE	BEAVER	CASTOR CANADENSIS TNGOP ( ) TNSIP ( )
CERVIDAE	WHITETAIL DEER	ODOCOILEUS VIRGINIANUS TNGOP ( ) TNSIP ( )
CRICETIDAE	MUSKRAT	ONDATRA ZIBETHICA TNSIP ( )
DIDELPHIIDAE	OPOSSUM	DIDELPHIS MARSUPIALIS TNGOP ( )
FELIDAE	BOBCAT	LYNX RUFUS TNGOP ( )
LEPORIDAE	EASTERN COTTONTAIL	SYLVILAGUS FLORIDANUS TNGOP ( )
MUSTELIDAE	MINK	MUSTELA VISON TNGOP ( ) TNSIP ( )
MUSTELIDAE	RIVER OTTER	LUTRA CANADENSIS TNSIP ( )
PROCYONIDAE	RACCOON	PROCYON LOTOR TNGOP ( ) TNSIP ( )
SCIURIDAE	EASTERN FOX SQUIRREL	SCIURUS NIGER TNGOP ( )
SCIURIDAE	EASTERN GRAY SQUIRREL	SCIURUS CAROLINENSIS TNGOP ( ) TNSIP ( )
VESPERTILIONIDAE	GRAY MYOTIS	MYOTIS GRISESCENS TNSIP ( )

APPENDIX C

INDEX TO BIRDS LOCATED ON MANAGED AREAS

PREPARED BY
THE NATURE CONSERVANCY

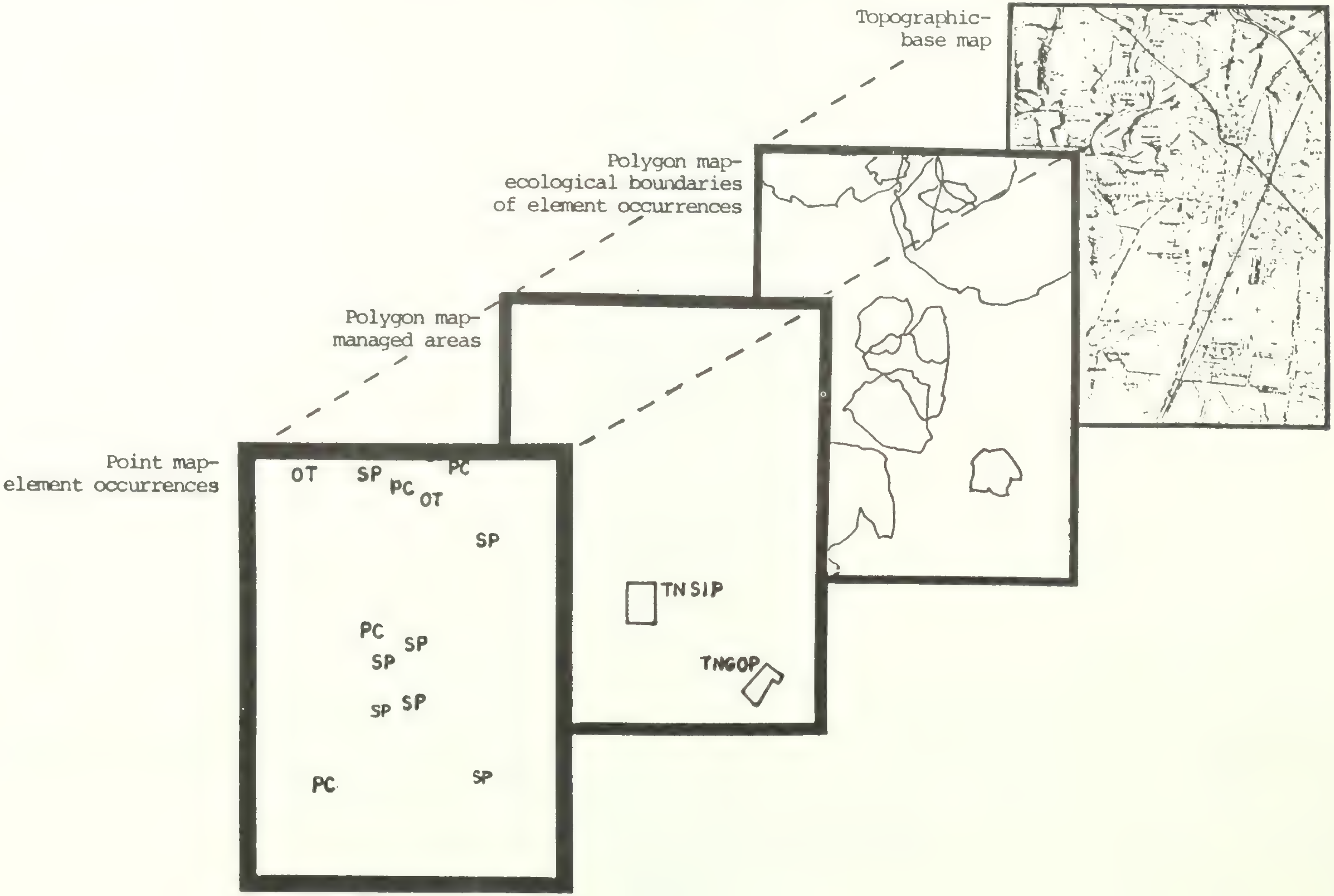
INDEX TO BIRDS BY COMMON NAME

PAGE 2
OCTOBER 1976

FAMILY NAME	COMMON NAME	SCIENTIFIC NAME SITE CODES
ANATIDAE	CANVASBACK	AYTHYA VALISINERIA TNGOP ( )
ANATIDAE	GREATER SCAUP	AYTHYA MARILA TNGOP ( )
ANATIDAE	LESSER SCAUP	AYTHYA AFFINIS TNGOP ( )
ANATIDAE	COMMON GOLDENEYE	BUCEPHALA CLANGULA TNGOP ( )
ANATIDAE	BUFFLEHEAD	BUCEPHALA ALBEOLA TNGOP ( )
ANATIDAE	RUDDY DUCK	OXYURA JAMAICENSIS TNGOP ( )
ANATIDAE	HOODED MERGANSER	LOPHODYTES CUCULLATUS TNGOP ( )
ANATIDAE	COMMON MERGANSER	MERGUS MERGANSER TNGOP ( )
ACCIPITRIDAE	GOLDEN EAGLE	AQUILA CHRYSAETOS TNGOP (R)
PANDIONIDAE	OSPREY	PANDION HALIAETUS TNGOP (R)
TETRAONIDAE	RUFFED GROUSE	BONASA UMBELLUS TNGOP ( )
PHASIANIDAE	BOBWHITE	COLINUS VIRGINIANUS TNGOP ( )
MELEAGRIDIDAE	TURKEY	MELEAGRIS GALLOPAVO TNGOP ( )
RALLIDAE	AMERICAN COOT	FULICA AMERICANA TNGOP ( )
SCOLOPACIDAE	AMERICAN WOODCOCK	PHILOHELA MINOR TNGOP ( )
SCOLOPACIDAE	COMMON SNIPE	CAPELLA GALLINAGO TNGOP ( )

APPENDIX D

ILLUSTRATION OF COMPUTER MAP OVERLAY CAPABILITIES SHOWING THE LOCATIONS OF ELEMENT OCCURRENCES, MANAGED AREAS AND ELEMENT OCCURRENCE BOUNDARIES THAT SHARE A COMMON TOPOGRAPHIC QUAD MAP


Topographic-base map
Polygon map-ecological boundaries of element occurrences
Polygon map-managed areas
Point map-element occurrences
OT
SP
PC
OT
PC
SP
PC
SP
SP
SP
SP
PC
SP
TN SIP
TNGOP

SUMMARY REMARKS

Harry N. Coulombe
National Habitat Assessment Group
U.S. Fish and Wildlife Service
Fort Collins, Colorado

Abstract: The scope of the concept of "habitat" as set forth in contemporary ecological literature is discussed. Thirty-one terms or phrases containing the word "habitat" are classed into four sets of concepts. These four themes are: life requisites for single species or species groups (guilds), resource allocation between (or within) species, spatial distribution of species or species groups, and quality of habitat for a species or species group. The relationships of these four concepts to applied natural resource management are explored.

The key term or concept around which we have assembled this symposium is the word "habitat." I have asked myself, "What useful contribution might I make in my summary remarks?" As I reflected on the various contexts and meanings that the word habitat was associated with during this symposium, I was prompted to review the history and evolution of this term, and concomitant concepts, into its present status within the ecological arena. I have become painfully aware in this exercise that the best application of my effort would very likely have been at the point of "introductory remarks" rather than in "summary." Nonetheless, my search to discover the roots, of what practicing ecologists agree is a most elastic term, became an intriguing task.

My objective was to seek an accepted, operationally definable concept or set of concepts. I shall attempt below to summarize briefly the scope of the concept of habitat as it has been institutionalized in the technical ecological literature in the past decade. I have also attempted to sort out several sets of concepts that derive their meaning and usefulness from the basic term habitat and have attempted to address, in a more cursory manner, the relationship of the term habitat to other interdependent ecological concepts and terminology. These classes of concepts, and related terminology, are summarized in Table 1.

CONCEPTS DEALING WITH LIFE REQUISITES

These uses of the term habitat and related terms in the context of the life requirements for organisms can broadly be dealt with in two classes. The first class deals with the levels of biological integration or organization above the single species level. In this context, perhaps the most referenced definition comes from Daubenmire (1968:4) in which he defines the following:

"Habitat (= ecotope = biotope) is usually used to denote a rather specific kind of living space or environment, i.e., a constellation of interacting physical and biological factors which provide at least minimal conditions for one organism to live or for a group (or organisms) to appear

Table 1. Classes of Concepts and Terminology Based Upon the Word "Habitat"
See Literature Cited for Complete References

Life requisites and associated literature

- A. Groups of species
  - habitat (Smith 1950, Elton and Miller 1953, Clarke 1954, Daubenmire 1959, Carpenter 1962, Dasmann 1964, Patrick and Reimer 1966, Daubenmire 1968, Ruttner 1969, Collier et al. 1973, Ricklefs 1973, Round 1973, Hynes 1976, Schwarz et al. 1976)
  - habitat type (Daubenmire 1959, 1968)
  - habitat form (Carpenter 1962)
  - major habitat (Allee et al. 1949, Pennak 1953)
  - habitat system (Elton and Miller 1953)
- B. Single species
  - habitat (Allee et al. 1949, Daubenmire 1959, Hutchinson 1967, Daubenmire 1968, Udvardy 1969, Owen 1971, Johnson 1973, Moen 1973, Smith 1974, Hynes 1976, Mead 1976, Williams et al. 1977)
  - microhabitat (Ricklefs 1973, Smith 1974)
  - habitat structure (Johnson 1973)
  - habitat feature (Elton and Miller 1953)
  - habitat attribute (Elton and Miller 1953)
  - habitat requirement (Dasmann 1964, Owen 1971, Williams et al. 1977)
  - habitat parameter (U.S. Fish and Wildlife Service 1976)
  - habitat component (Elton and Miller 1953)
  - critical habitat[a]

Resource allocation between species

- habitat selection (Allee et al. 1949, Udvardy 1969, Krebs 1972)
- habitat breadth (Ricklefs 1973)
- habitat preference (Ricklefs 1973)
- habitat partitioning (Ricklefs 1973)
- habitat specialization (Ricklefs 1973)

Table 1. (Concluded)

- Spatial distribution of species or species groups
  - habitat (Allee et al. 1949, Onions 1955, Cain and de Oliveira 1959, Carpenter 1961, Hanson 1962, Kenneth 1966, Hutchinson 1967, Whittaker 1970, Moen 1973, Slack et al. 1973, Schwarz et al. 1976, Williams et al. 1977)
  - habitat type (Allee et al. 1949, Ricklefs 1973, U. S. Fish and Wildlife Service 1976)
  - habitat niche (Allee et al. 1949, Odum 1971)
  - optimal habitat (Udvardy 1969)
  - preferred habitat (Udvardy 1969)
  - inferior habitat (Udvardy 1969)
  - breeding habitat (Elton and Miller 1953, Udvardy 1969, Hynes 1976)
  - seasonal habitat (Dasmann 1964, Owen 1971)
  - habitat group (Carpenter 1962)
  - habitat space (Kenneth 1966, Johnson 1977)
- Quality of habitat for a species or species group
  - marginal habitat (Williams et al. 1977)
  - optimal habitat (Udvardy 1969, Williams et al. 1977)
  - inferior habitat (Udvardy 1969)
  - favorable habitat (Allee et al. 1949, Udvardy 1969)
  - habitat capability (Dasmann 1964, Owen 1971)
  - habitat suitability (Elton and Miller 1953, Williams et al. 1977)
  - habitat quality (U. S. Fish and Wildlife Service 1976)
  - habitat evaluation (Moen 1973, U. S. Fish and Wildlife Service 1976)

---

[a] This term has specified meaning associated with the Endangered Species Act of 1973 (16 U.S.C. 1532)

together. The scope of the term is very elastic. One may with equal justification describe the habitat of a particular clone of *Dicranum fuscescens* (a bark moss) as being (1) the bark of *Tsuga mertensiana* (mountain or black hemlock) tree, (2) a forested ravine, or (3) the subalpine zone of the Olympic Mountains."

As Daubenmire (1968) notes, the terms biotope and ecotope are, in his opinion, synonymous with the term habitat. Other authors consider the concept of habitat to include physical environmental attributes and biological life requirements, such as the presence of prey species for a predator. The general use of the word environment includes all of the external factors that impinge upon an organism, including competition, thermodynamics, energy balance, and other biological relationships (Moen 1973).

The terms *major habitat* and *microhabitat* have been used to distinguish various subsets of physical environmental factors; in Daubenmire's (1968) definition quoted above, the bark of the mountain hemlock would commonly be accepted as an example of microhabitat (Moen 1973:114). Major habitat or habitat system are related, respectively, to the second and third levels of resolution indicated in Daubenmire's (1968) definition given above (Allee et al. 1949, Elton and Miller 1953, Pennak 1953).

Daubenmire and others have generally used the term *habitat type* to indicate the presence of appropriate physical factors for a particular type of plant species. It should be noted that Daubenmire prefers to apply the term habitat type to a geographic area or distribution (Daubenmire 1959, 1968). This use is discussed later under the heading Concepts Dealing with Spatial Distribution of Species and Species Groups.

Among wildlife biologists perhaps the most widely used context of the term habitat is that concerned with the life requirements of a single species or of some population of a particular species. The terms *habitat* and *microhabitat* have all been used in this particular context. It is within this use that we encounter such terms as *habitat structure*, *habitat attribute*, *habitat requirement*, and other related terms (Elton and Miller 1953, Dasmann 1964, Owen 1971, Johnson 1973, Williams et al. 1977). For practical reasons it is useful to subdivide the living space of a population into classes of components that, when summed, equal the external life requirements of a given species. The terminology varies widely throughout the literature; however, the fundamental use of such component-related labels seems to be fairly consistent. The physical, nonmobile attributes of a particular landscape are generally inventoried or addressed when we deal with *habitat components* (Elton and Miller 1953). Although many professionals include the broad environment concept when discussing habitat components (Hanson 1962, Johnson 1973, Schwarz et al. 1976), others prefer a clearly defined distinction (Odum 1971, Collier et al. 1973, Moen 1973).

A relatively recent term that has crept into the institutions of professional wildlife management is the concept of *critical habitat*. As defined, critical habitat delineates some area within the geographic range of a sensitive species that is thought to be the minimum landscape area required to maintain a viable population. This is a specific use of terms that has been institutionalized by Congressional mandate and is appropriate for this particular purpose (see footnote Table 1). The critical habitat concept has not been used to identify the critical components of life requirements of a species.

CONCEPTS DEALING WITH RESOURCE ALLOCATION BETWEEN SPECIES

In the 1960's ecologist Robert McArthur introduced a set of ecological concepts dealing with the modes by which species partition environmental resources. These ecological concepts were centered around (1) the mechanisms by which interspecific competition is minimized and (2) the mechanisms causing species replacement and faunal changes. Insights to the nature of resource factors limiting specific populations were synthesized (Elton and Miller 1953). The concepts fall somewhat into two categories: the first deals with mechanisms that lead to genetic selection of characteristics of animals, whereas the second deals with learned or acquired behavior of individual animals enabling them to adjust to the biological setting within which they must carry out their life functions.

Habitat selection is a specific concept that is longstanding in the ecological literature (Allee et al. 1949, Krebs 1972, Williams et al. 1977). The basic precepts are that many species of animals demonstrate genetically determined mechanisms by which dispersing individuals recognize the physical aspects of the landscape within which their life requirements can be met. This is an important concept in determining the ability of certain species of organisms to successfully establish themselves in geographic areas totally outside of their natural distribution, by the virtue of being preadapted to survive in a new area (Ricklefs 1973). Some clues to the specific attributes of the landscape that are used by species to activate the mechanism of habitat selection have been discovered in the study of passerine birds (Udvardy 1969, Krebs 1972, Ricklefs 1973). One example is the nesting requirements of the green-tailed towhee (Chlorura chlorura), which breeds successfully over a wide geographic area of the Rocky Mountains and intermountain valleys. The plant communities and the species of plants within which the green-tailed towhee nests are quite diverse; however, the structural aspects of the vegetation such as life form, denseness of crown closure, and diversity of foliage height seem to be consistently similar for this species.

The term habitat preference has been used in the resource manager's field generally to indicate the result of the mechanism of habitat selection (Udvardy 1969, Ricklefs 1973). In the ecological literature, the concept of habitat preference has been used at times to indicate that individual organisms behaviorally acquire an affinity for specific aspects of the landscape within which they reside (Krebs 1972, Ricklefs 1973). Different individuals within the same population may show a wide variety in the preferences expressed, as evidenced by the amount of time spent in various categories of physical attributes (Udvardy 1969). Over the past decade, numerous wildlife studies, utilizing radiotelemetry to determine the kind, location, and duration of activities of population members, have underscored the individualistic nature of many vertebrates--ranging from killer whales (Orcinus orca) to largemouth bass (Micropterus salmoides) and from moose (Alces alces) to deer mice (Peromyscus maniculatus). The basic feature seems to be that organisms capable of learning tend to emphasize positive experiences in finding food, shelter, or water (Krebs 1972).

The concepts of resource allocation have entered the arena of habitat-related terminology with such phrases as habitat partitioning, habitat breadth, and habitat specialization to demonstrate the ways in which species faced with limited environmental resources, divide food, space, and time to maximize the benefits for each population in a given landscape area (Ricklefs

1973). The term habitat specialization has been used primarily to indicate species that have relatively restricted ranges of ecological needs and is a direct corollary of the general evolutionary concept of specialization. Similarly, the term habitat breadth, although used to describe the scope of habitat attributes occupied by a particular species, has mainly been used as an analog to the evolutionary concept of generalization.

The concepts dealing with resource allocation between species may have their greatest significance to the practice of wildlife management as they relate to the concept of carrying capacity. Many times we assume that if we select a particular species of direct economic interest to man, such as mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*), or other species that we consume, that we can increase the amount of resources present in a given piece of landscape for the benefit of a particular featured species. Many ecologists would counter with the argument as follows: because of the mechanisms of ecosystem function and, in particular, the concepts of *habitat partitioning* among many species occupying a given landscape unit, all we really accomplish is tipping the balance of resource allocation for the advantage of one species or species group at the expense of some other group or species. In most cases our management practices do not significantly increase the overall net productivity of an area, but rather are focused at sustaining the successional stage of a given biological community.

CONCEPTS DEALING WITH SPATIAL DISTRIBUTION OF SPECIES OR SPECIES GROUPS

Odum (1971:234), in his discussion of the concept of *habitat* and *ecological niche*, likes to define habitat in the context of "...the place where it (a species) lives, or the place where one would go to find it." He further defines the concept of ecological niche as a more inclusive term that includes not only the physical space occupied by an organism but also its functional role in the community and its position in terms of environmental gradients such as temperature, moisture, pH, and other conditions of existence. Odum defines a subset of the ecological niche, which he conveniently designates the habitat niche or its spatial niche, as the place where an organism lives. This is analogous to the early work of Charles Elton (the renowned British animal ecologist) who considered an organism's *habitat* as defining its "address," whereas its *niche* defined the organism's "profession" (Elton and Miller 1953). Thus, the basis is set for a class of uses of habitat-related terms that basically connote a spatial dimension within the geographic distribution of a species--the place where one would go to find the organism.

Related terms are used to convey indirectly the probability of finding the organism when one goes to its "address" or to imply some gross level of abundance of the species. *Optimal habitat*, *marginal habitat*, and *inferior habitat* are such phrases (Udvardy 1969, Williams et al. 1977). These phrases imply some level at which the life requirements of an organism may be met within defined spatial boundaries. They may operationally define the probability that a species maintains a viable, reproducing population (Udvardy, 1969). From the zoogeographer's standpoint, it is important to know whether or not a place is a marginal geographic locality for a species population (where it may not successfully reproduce) and if the population may temporarily become extirpated.

Such terms as breeding habitat or various kinds of seasonal habitat are another subset of habitat terminology basically dealing with the spatial distribution of a species (Elton and Miller 1953, Daubenmire 1968, Udvardy 1969, Owen 1971, Hynes 1976). Many species that exhibit pronounced seasonal changes in habitat selection, as evidenced by regular migrations, are spatially distributed in different locations throughout an annual cycle (Udvardy 1969). A basic corollary of the seasonal habitat concept is that many organisms may not physically occupy the same geographic space throughout the year or throughout all stages of their life history. Thus, the resource manager must be aware of the seasonal potential or actual use of a given piece of ground, even though certain species may not be physically present when the evaluation is conducted on a given site.

CONCEPTS DEALING WITH QUALITY OF A HABITAT FOR A SPECIES OR GROUP OF SPECIES

Several terms previously discussed with respect to spatial-distribution concepts have appeared in this general area of application: optimal habitat, marginal habitat, and inferior habitat. In a geographic-distribution context these terms have occasionally been operationally defined to indicate the level of success in colonization by species (Udvardy 1969). In the present context the terms imply some level (quality) to which a given landscape unit satisfies one or more of the life requirements for a species population, a guild, a life-form group, or some other association of species (Williams et al. 1977). The implication is that a quantitative correlation can be made between some level of "habitat quality" and the size of the population of organisms in question, or the diversity of a group of organisms, or some other aspect of population-based performance, such as recruitment, productivity, or the quality (e.g., healthiness, growth rate) of individual organisms (Elton and Miller 1953, U.S. Fish and Wildlife Service 1976, Williams et al. 1977). Qualifiers such as preferred vs. inferior, or optimal vs. marginal, when used with the term habitat, generally have utility in classifying landscape areas into two levels of expected abundance of the organism in question. These essentially dichotomous distinctions are subdivisions of the general concept of habitat quality (U.S. Fish and Wildlife Service 1976). Perhaps more useful in our current attempts to quantify the decisionmaking process in natural-resource management is the use of a series of classes or categories to imply defined levels of ability of a given landscape unit, or feature within the unit, to supply the life requisites for specific organisms (Williams et al. 1977).

The terms habitat capability and habitat suitability also have appeared in contemporary use (Elton and Miller 1953, Dasmann 1964, Owen 1971, Williams et al. 1977). In most cases, the concepts of habitat capability imply a series of classes (more than two) of landscape areas that grade in their ability to provide life requisites (Dasmann 1964, Owen 1971). From my understanding of population dynamics, the concept of carrying capacity is very closely related with the application of the concept of habitat capability (Dasmann 1964, Williams et al. 1977). Again, wildlife managers imply a quantitative correlation between some rank of habitat capability and the numerical carrying capacity of a landscape area, with reference to its management potential. Habitat suitability has, in some cases, been used synonymously with its sister phrase, habitat capability (Elton and Miller 1953, Williams et al. 1977). However, it may be useful to distinguish between the practical use of terminology, indicating the management potential of a given landscape unit, as opposed to its present or current ability to provide life requisites for particular species. The logical process of identification, inventory, and analysis may be similar to trying to define differences in the concepts suitability vs. capability of habitat. Recent approaches to the diagnosis of the attributes of landscape areas, such as the application of pattern-recognition algorithms, cluster analysis, and other automatic data processing approaches, indicate the parameters necessary for identifying the current status of an area of wildlife use, that are essential to focusing on the particular attributes that may be modified to manage specific populations (U.S. Fish and Wildlife Service 1976, Williams et al. 1977).

The conceptual process of translating habitat quality into human value judgments (habitat evaluation) should be founded on our best professional information (U.S. Fish and Wildlife Service 1976); this translation, or inference, can be quantifiable. However, the directly measurable attributes upon which the evaluation is based are from entirely different perspectives. Intrinsic ecological values, judged either from a community perspective or from a sum-of-indicator-species perspective is the point of departure for assessing habitat quality (Elton and Miller 1953, U.S. Fish and Wildlife Service 1976, Williams et al. 1977).

RECOMMENDATIONS FOR HABITAT-RELATED TERMINOLOGY

The use of phrases containing the word habitat represent more clearly defined concepts than does the single term habitat in the ecological literature. The four classes of concepts previously discussed in this paper all contribute useful insights or practical labels to the tasks of decisionmaking in natural resource management. I suggest that most of the confusion discerned by the wildlife practitioner is due to the degree of overlap between the four general concepts in many specific applications of habitat terminology. I will try to make some suggestions that will perhaps lead us toward increased clarity of communication.

In the process of analyzing various features of the landscape that we can translate into quantitative wildlife relationships, two aspects should remain conceptually distinct. One must make the careful distinction between our objective analysis of what exists, or is directly measurable, and the process by which one places values on these measurements. The concept habitat evaluation should be reserved to the process by which one transfers value. For example, one can analyze growth of leaders on shrubs and quantitatively display these results to indicate some level of standing crop for a group of browsing ungulates that might be supported.

When we indicate that these measurements indicate poor, good, or some other value class, we have added value judgment from the human perspective. The key is to structure the process of arriving at values for wildlife habitat units through the quantitative analysis of habitat parameters. These attributes can quantitatively relate to a biological measurement such as population size or productivity.

The phrase habitat suitability is perhaps a useful process by which to relate quantitative measurements of various landscape features to their measurable relationship to wildlife quality, as defined by population size or some other population attribute. I favor the term habitat capability to refer to our professional judgment or projection as to the appropriate potential of a given site--its management potential from the perspective of manipulating the current wildlife population to some new level of a directly measurable objective without invoking the human value judgment. This can involve objectives such as increased species richness, or altered equitability of diversity, as well as potential for changes in standing crop or productivity of traditional featured species.

In order to analyze habitat suitability and habitat capability, one needs to couple the measurable features of the site or area with the life requisites of a species population or an association of species. Terms such as habitat feature, habitat attribute, and habitat component all seem equally suited to this particular designation. The point I would like to make is that life requisites for a species or species group must be translated from some measurable features of the landscape. When this coupling has been made, then that particular feature of the landscape has meaning with respect to meeting the requirements of a particular species in terms of expressing the expected or actual population size or productivity on that site. The word habitat by itself is best avoided in this particular use.

The ability of some landscape area to provide the life requisites for a group of species may be approached either by summing our knowledge of the ability of that area to provide life requisites for a list of single species or approached through the life-form or guild concept. Again the word habitat is not very communicative in this regard; habitat form or habitat system may be appropriate for delineating a mappable unit that conveys the ability of some area to provide the life requisites for groups of species.

Habitat type may be best used to indicate the potential (climax) plant community present at the site. If we must use it in the wildlife arena, it should be the designation of the stable association of wildlife and vegetation expected in some prescribed geographic area. "Stable" can be operationally defined; for example, it is the most frequent association found during 100 years in the area.

The biogeographers have indicated an interesting concept that deals with the true marginal habitat of species or that area which is under advanced colonization. The term optimal habitat may be useful in connoting the spatial distribution of a species or species group within the boundaries of which we are confident that the life requisites may be met for self-sustaining, reproducing units. Marginal habitat connotes that there is a probability that populations may be transient over time, or that there are some clearly defined probabilities of successful establishment, reproductive attempts, and successful reproduction associated with such areas. Further, it may be useful to divide areas of optimal habitat, in terms of distribution into various habitat units that reflect seasonal use or special use such as breeding habitat.

Most authors indicate that habitat implies a spatial dimension (something that can be mapped). I think it is useful to distinguish between certain terms and, in some cases, concepts that do not imply a spatial dimension. The concept dealing with resource allocation between species, centered around the mechanism of habitat selection, is certainly useful; and the various phrases dealing with this concept are among the most clearly defined phrases that I encountered. Certainly if one were advanced sufficiently in our knowledge of life requisites for wildlife, one would choose the physical attributes of the landscape that the research community says are the key or triggering stimuli that invoke the process of habitat selection which in turn may reveal habitat attributes that we analyze as wildlife managers. Mechanisms of resource allocation between species and within species are useful to us in determining strategies for managing or manipulating our natural resources.

CONCLUDING THOUGHTS

Over the course of the several days of the symposium, many stimulating thoughts and innovative ideas have been presented. In fact, so many that it would be a futile gesture for me to try to summarize here the many excellent presentations. Some of my own impressions I will now elucidate.

The need for natural resource managers to communicate their concerns to all elements of society and at all decisionmaking levels from practice to policy is certainly apparent to all of us. To facilitate this communication, one first leans to the process of classification--the area of endeavor within which one attempts to standardize our terminology driven by the real need to structure concepts, data collection, and the analysis process to yield information for the decisionmaking process. This process of structuring or labeling is certainly necessary to design the application of new and emerging technologies, to take stock of our natural resources and their condition, and to set up an account by which we can quantify losses or gains of our renewable stocks.

There is also a need to ecologically characterize land units. The process requires integration of existing ecological knowledge into a framework. From this we can prioritize the needs for the inventory of new information and specify the frequency of updating the state of knowledge about other aspects of our resources. The pervasive need for the orderly structuring of our approach to the analysis of information about fish and wildlife habitat is most apparent in our discussions of information-management needs. The ability of an individual's mental scope to quantitatively track various parameters, to make some prediction or judgment of value for the decision process, is limited. A realistic goal may be to use computers to attempt mimicking the intuitive process that the on-the-ground wildlife manager uses in making his predictions and professional judgments.

It is becoming clear that when we analyze habitat characteristics we need to make assessments and predictions concerning ecological processes. Changes in ecological system attributes, such as the interactions between species, system stability, the rate and direction of succession and changes in trophic structures, are important considerations for large-area planning. Other properties of ecosystems such as net primary productivity, nutrient-pool size, or nutrient-turnover rates are becoming increasingly important as we look at our options for managing wildlife resources in relation to impacts of our technology and social actions. A major need is to state appropriate ecological paradigms in forms that we can utilize in structuring the information and the analyses we make about our on-the-ground systems.

I am impressed by the fact that a major challenge in our approaches to ecological relationships may be constrained by a common building block of ecological science. That is, most of our techniques for inventory, analysis, and even classification, are the products of graduate student research. The constraints placed upon student projects, such as time, geography, funding, and scope of input, perhaps defeat the basic intent. Yet most of our standard techniques for analyzing populations and aspects of their habitat requirements are determined from the same procedures devised in our system for training new professionals. From the resource managers' point of view, the science (or art) of ecology certainly has its strength in a holistic rather than an atomistic approach. I hope that the next decade in the development of applied ecological theory will focus on an integrative approach to the development of working hypotheses that can become practical, efficient, and effective operational tools for our resource managers.

LITERATURE CITED

Allee, W. C., O. Park, A. E. Emerson, T. Park, K. P. Schmidt. 1949. Principles of Animal Ecology. W. B. Saunders Co., Philadelphia. 837 pp.

Cain, S. A., and G. M. de Oliveira Castro. 1959. Manual of Vegetation Analysis. Harper and Brothers Publ., New York. 325 pp.

Carpenter, J. R. 1962. An Ecological Glossary. Hafner Publ. Col, New York and London. 306 pp.

Clarke, G. L. 1954. Elements of Ecology. John Wiley and Sons, Inc., N.Y.

Collier, B. D., G. W. Cox, A. W. Johnson, and P. C. Miller. 1973. Dynamic Ecology. Prentice-Hall, Inc., Englewood Cliffs, New Jersey 563 pp.

Dasmann, R. F. 1964. Wildlife Biology. John Wiley and Sons, Inc., New York.

Daubenmire, R. F. 1959. Plants and Environment: A Textbook of Autecology. 2nd Ed. John Wiley and Sons, Inc., New York. 422 pp.

Daubenmire, R. F. 1968. The Nature of Plant Communities: A Textbook of Plant Synecology. Harper and Row Publ., New York. 300 pp.

Elton, C. S., and R. S. Miller. 1953. The ecological survey of animal communities: with a practical system of classifying habitats by structural characters. J. Ecology 42:460-496.

Hanson, H. C. 1962. Dictionary of Ecology. U. S. Philosophical Library.
Hutchinson, G. E. 1967. A Treatise on Limnology: Volume II Introduction to Lake Biology and the Limnoplankton. John Wiley and Sons, Inc., New York.

Hynes, H. B. N. 1976. The Ecology of Running Water. Univ. Toronto Press, Canada. 555 pp.

Johnson, A. W. (ed.) 1973. An Ecological Glossary for Engineers and Resource Managers. The Inst. Ecology, Washington, D.C. 50 pp.

Johnson, P. L. (ed.) An Ecosystem Paradigm For Ecology. Oak Ridge Associated Universities, Oak Ridge, Tennessee. ORAU-129. 20 pp.

Kenneth, J. H. (ed.) 1966. Dictionary of Biological Terms. Oliver and Boyd Ltd., Edinburgh, England. 640 pp.

Krebs, C. J. 1972. Ecology: The Experimental Analysis of Distribution and Abundance. Harper and Row, Publishers, New York. 694 pp.

Mead, M. 1976. Habitat. Science 192:4243.

Moen, A. N. 1973. Wildlife Ecology. W. H. Freeman and Company, San Francisco, California. 458 pp.

Odum, E. P. 1971. Fundamentals of Ecology. 3rd Ed. W. B. Saunders Co., Philadelphia. 574 pp.

Onions, C. T. (ed.) 1955. The Oxford Universal Dictionary. Oxford Univ. Press, London. 2,515 pp.

Owen, O. S. 1971. Natural Resource Conservation: an Ecological Approach. The Macmillan Co., New York. 593 pp.

Patrick, R., and C. W. Reimer. 1966. The Diatoms of the United States. Volume I. Livingston Publ. Co., U. S. 688 pp.

Pennak, R. W. 1953. Fresh-Water Invertebrates of the United States. The Ronald Press Co., New York. 769 pp.

Ricklefs, R. E. 1973. Ecology. Chiron Press, Inc., Newton, Massachusetts.

Round, F. E. 1973. The Biology of the Algae. Edward Arnold Ltd., London.
Ruttner, F. 1969. Fundamentals of Limnology. Univ. Toronto Press, Canada.

Schwarz, C. F., E. C. Thor, and G. H. Elsner. 1976. Wildland Planning Glossary. U. S. Forest Serv. Gen. Tech. Rep. PSW-13. Pacific Southwest Forest and Range Exp. Stn., Berkeley, California. 252 pp.

Slack, K. V., R. C. Averett, P. E. Greeson, and R. G. Lipscomb. 1973. Techniques of Water-Resources Investigations of the United States Geological Survey. Chapter A4. Methods for Collection and Analysis of Aquatic Biological and Microbiological Samples. Book 5. Laboratory Analysis. U. S. Dept. Interior. Geological Surv. U. S. Gov. Printing Off., Washington. 165 pp.

Smith, G. M. 1950. The Fresh-Water Algae of the United States. McGraw-Hill Book Co., New York. 719 pp.

Smith, R. L. 1974. Ecology and Field Biology. Harper and Row, Publ., New York. 850 pp.

Udvardy, M. D. F. 1969. Dynamic Zoogeography: With Special Reference to Land Animals. Van Nostrand and Reinhold Co., New York. 445 pp.

U. S. Fish and Wildlife Service. 1976. Habitat Evaluation Procedures: For Use by the Division of Ecological Services in Evaluating Water and Related Land Resource Development Projects. U. S. Fish and Wildl. Ser., Washington, D.C. Mimeo, Rep., 30 pp.

Whittaker, R. H. 1970. Communities and Ecosystems. The Macmillan Co., Collier-Macmillan Ltd., London. 158 pp.

Williams, G. L., K. R. Russell, and W. K. Seitz. 1977. Pattern recognition as a tool in the ecological analysis of habitat. Colorado Coop. Wildl. Res. Unit. Mimeo. Rep. 16 pp.

3 1604 004 720 712

DATE DUE

JAN 1 8 1995			
Ret'd. JAN 18 '95			

Demco, Inc. 38-293

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

March 3, 1849

Office of Biological Services
Fish and Wildlife Service
U.S. Department of the Interior
Washington, D.C. 20240

Official Business
Penalty for Private Use $300

U.S. MAIL

Postage and Fees Paid
U.S. Department of the Interior
INT 423